A STUDY OF THE EFFECT OF DELINEATION ON TRAFFIC SPEED PATTERNS

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by

L. D. POWERS

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Final Report

A STUDY OF THE EFFECT OF DELINEATION ON TRAFFIC SPEED PATTERNS

TO: K. B. Woods, Director
Joint Highway Research Project

May 14, 1953

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

File: 4-4-11
Project: C-36-17F

Attached is a final report entitled, "A Study of the Effect of Delineation on Traffic Speed Patterns," by L. D. Powers, graduate assistant on our staff. This research was also utilized by Mr. Powers as part of the requirements of the M.S.C.E. degree. The research was directed by Prof. H. L. Michael.

This research project investigated the effect of delineation on driver characteristics, especially speed, at three locations where vehicle conflicts were appreciable. The study was actually the initial one of several which are planned. A before and after accident study at the three locations should now be conducted to evaluate this aspect of delineation. It is also hoped that an illumination study at these locations can be performed so that the characteristics under illumination can be compared with those which were found under good delineation.

The report is submitted for the record.

Respectfully submitted,

H. L. Michael, Secretary

HLM:ac

Attachment

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Final Report

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By

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ABSTRACT

Powers, Lawrence David. MSCE., Purdue University, June 1959. A STUDY OF THE EFFECT OF DELINEATION ON TRAFFIC SPEED PATTERNS. Major Professor: Harold L. Michael.

Delineation has been recognized as a useful tool in attempting to counteract the decrease in visibility attendant with the hours of darkness. In some circumstances it can be used as an inexpensive substitute for illumination. Little work has been done, however, in regard to the relationship between visibility and speed.

This thesis reports the results of a study at three distinctive locations of the combined effect of various forms of delineation on driver speed patterns. The locations concerned were a narrow bridge, a hazardous intersection, and an adequate intersection, all in rural areas. The various forms of delineation under consideration were roadside reflectors, pavement edge lines, signing, and, in one case, channelizing islands. Only free-moving passenger cars travelling on dry pavement under optimum day or night visibility conditions were considered. In the case of one location heavy commercial vehicles were also recorded; however, speed patterns for cars and trucks were analyzed separately. Spot speeds were recorded, using Electro-matic radar speedmeters, at various points at each location during the day, at night, and again at night after the additional delineation had been installed. From 30 (for heavy trucks) to 300 or more observations, depending on the estimated variability of the speeds and prevailing traffic volumes, were made for each movement. Altogether, over 25,000 vehicles were recorded.

The study showed that passenger car speeds were lower at night than during daylight hours. Truck speeds, however, increased in some places and decreased in others. Variabilities of the speed distributions were not markedly changed from day to night.

The study also indicated higher night speeds on the part of passenger cars after the addition of delineation. Acceleration and deceleration were apparently delayed or diminished in the vicinity of critical features resulting in, for the most part, more uniform speed profiles through the locations. Variabilities in the speed distributions at the individual stations were largely unaffected.

Truck speeds were not markedly affected in any way, at least as far as could be determined from the limited data available.

Any differences noted, however, between speeds before and after delineation had been added were small, the average for all stations being less than plus two miles per hour, and the practical significance of these differences is probably quite small.

INTRODUCTION

Night Driving and Visibility

It is generally agreed that night driving is far more hazardous than that during daylight hours. One has only to compare daytime and nighttime accident rates for confirmation of this. Nighttime travel makes up only 30 percent of total rural travel, yet it accounts for 70 percent of rural motor vehicle fatalities(7)*.

The causes of this disproportionate difference in accident rates can easily be assigned. Fatigue and intoxication are more likely to be prevalent at night and a greater percentage of nighttime travel will consist of long distance trips and non-local drivers. However, the primary factor conducive to accident exposure is, literally, the difference between night and day: the difference in visibility! During the hours of darkness, clarity and distance of vision are sharply curtailed, but, unfortunately, driving characteristics are not altered accordingly. For this reason darkness constitutes an additional hazard to traffic safety.

One remedy of this situation would be to attempt to reproduce daylight conditions by means of highway illumination, as in urban areas. The cost of providing adequate illumination to any large extent over the rural highway system would, however, be prohibitive. Some other means of enabling the driver to "see ahead" must be provided.

A method which has been finding favor recently is the use of roadside reflectors and pavement edge lines as aids to the discernment of the course of the roadway. These devices serve, not to illuminate the roadway, but to outline, or delineate it.

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*Numbers in parentheses refer to listings in the bibliography.

Speed and Safety

In order to justify the increases in highway speeds attendant with the early growth of the use of motor vehicles, and in an attempt to refute the then current arguments that such speeds were dangerous, this maxim was promulgated: "Speed, per se, is not a causative factor in accidents."(4)

Experience has shown that this statement is not always entirely correct. Certainly, higher speeds will increase the chances of exposure to situations which could lead to an accident by increasing the rapidity with which such situations develop and by decreasing the driver's ability to recognize and react to them. The speed will also determine the severity of an accident.

Fortunately, the above statement has since been modified to: "Speed is only dangerous relative to attendant conditions."(4)

The phrase "relative to attendant conditions" is the crux of the following discussion.

Speed and Visibility

The only limitations on speed, when it is not limited by the characteristics of the highway or by traffic, will be those imposed by the driver, by limitations of the vehicle, or by posted limits. There are many locations where the characteristics of the highway do, or rather should, impose an additional limit on what may be considered a safe speed, particularly at night when visibility is sharply decreased.

In a 1956 study in England, an attempt was made to correlate road layout with speeds and accidents(2). It was reported that the effect of horizontal curvature was to reduce the average speeds of

both passenger cars and commercial vehicles 3.07 and 1.67 miles per hour, respectively, for each 100° of average curvature per mile. It was the opinion of the authors that a large amount of the effect could be attributed to low visibility (i.e., sight distance).

Though warning signs and advisory speeds are posted at many hazardous locations, there may still be insufficient information supplied to the motorist. It has been shown that the good driver will vary his driving characteristics according to existing conditions rather than according to traffic controls(3). It follows that he must be made aware of these conditions before he can react to them.

Where there is doubt as to the nature of conditions ahead, caution would dictate a policy on the part of the driver of going slow. Most drivers, however, prefer to drive at a uniform speed, thereby running the risk of unknowingly continuing at a speed too great for existing conditions, and not realizing it until too late. The speed differential between the overly cautious motorist and the incautious one may add to the existing hazards.

There is no conclusive evidence, however, to show that accident frequency is related to the magnitude of speed. The majority of accidents are caused by inattention, fatigue, and poor judgment, which factors are present on high and low speed facilities alike. These factors contribute to speeds which are not safe for the conditions. It is reasonable to assume, therefore, that the better informed and alert the driver is, the better he will be able to achieve a safe speed.

Speed and Delineation

It has been found that the installation of illumination at high accident intersections has considerably reduced the night accident rate(1). In addition to enhancing visibility, lighting may serve as a warning indication, alerting the driver to critical areas.

In the case of delineation, visibility in terms of clarity of vision is unaffected, but the benefits of advance warning and attention-getting are retained.

The question remains, however, as to how much of an impression delineation will make upon the driver. Just as we cannot directly measure stress in a structural member, but must calculate it by measuring strain, we cannot directly measure driver reaction to traffic control devices, but must infer it by noting whether the effect manifests itself in a variation in driving characteristics. One of the most important measures of traffic behavior is vehicle speed.

How, then, will delineation affect vehicle speeds? Will the driver tend to maintain open highway speed or fail to decelerate sufficiently at hazardous locations because of a feeling of confidence inspired by his believing himself better able to discern conditions ahead? Or, will he tend to decrease his speed through the association of delineation with hazard?

There is the possibility that the sole reaction will be increased alertness, with no apparent change in driving characteristics. This would certainly be beneficial, but, unfortunately, not easily measured except by a long term accident study.

Any of these possible effects would undoubtedly vary with the degree that the individual driver is familiar with the location

involved and might result in a change in the dispersion of the speed distribution. Since local drivers would be familiar with the location, their speeds would, presumably, not be affected by the addition of delineation. One would hope that such delineation would result in a reduction in the frequencies of the excessively high and low speeds. The optimum condition to be achieved would be to have every vehicle travelling at the same speed, this speed being the maximum safe speed.

Since it is likely that the effect of delineation on drivers would be an individual one, the percentage of local drivers at any one location would determine the intensity of the effect at that location and results would vary from one location to another.

Speed - Delineation Study

This study is an attempt to provide information to answer these questions by measuring the effects of delineation on traffic speed patterns at locations which could be considered potentially hazardous, either because of geometric inadequacies or because they represent points of conflict or friction in the traffic stream.

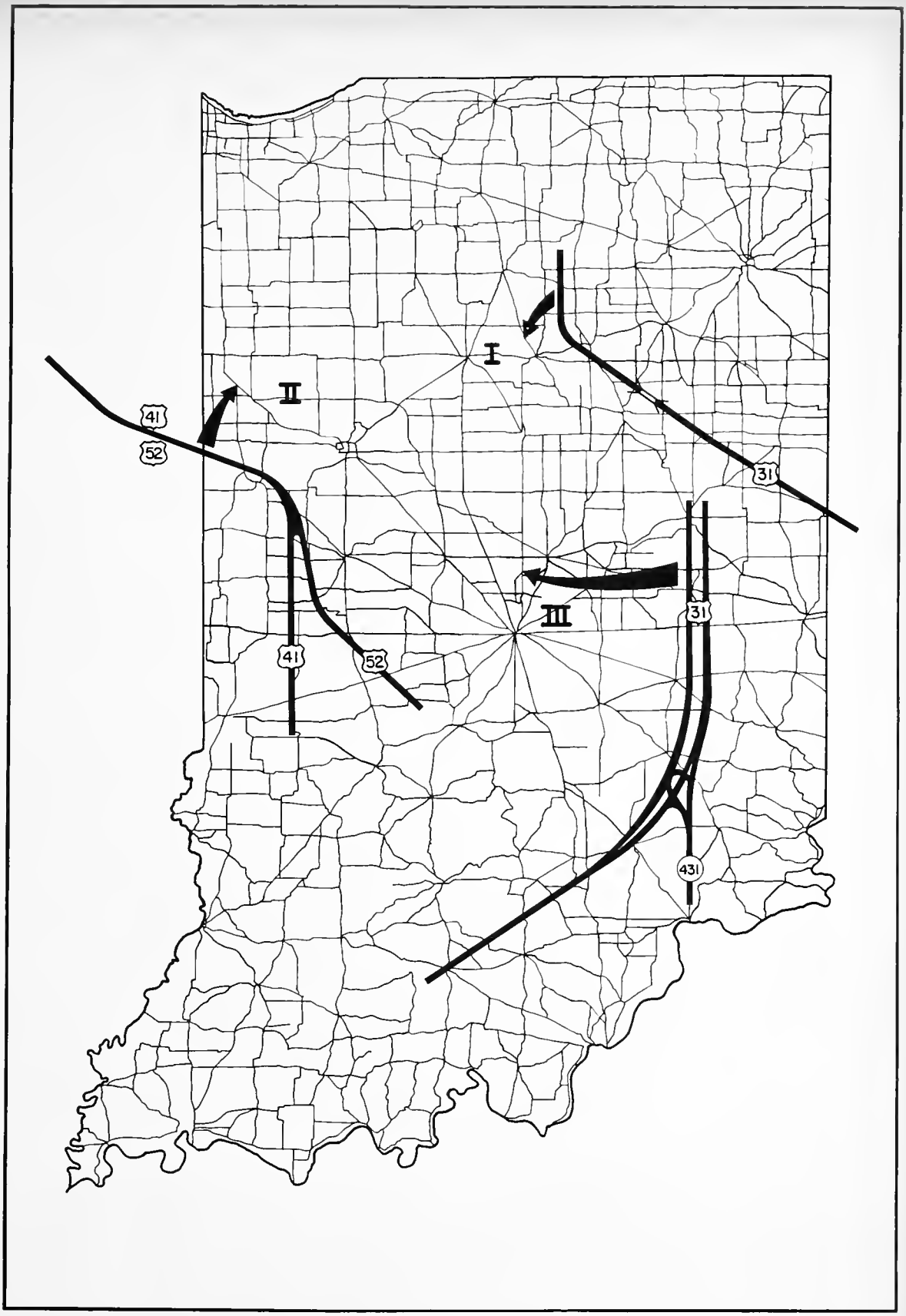
The study was performed at three distinctive locations: a narrow bridge, a hazardous intersection, and an adequate intersection. All the locations are on rural trunk highways. However, a comparison between them would be made difficult by a lack of relative before conditions. The study began with differences in existing delineation between the locations and the needs for additional delineation at each were not the same.

Figure 1 shows these locations in relation to Indiana's highway system. Aerial photos of the locations and the stations

(as indicated by letters) at which speeds were measured are shown in Plate I. These locations will be discussed in detail in a later chapter.

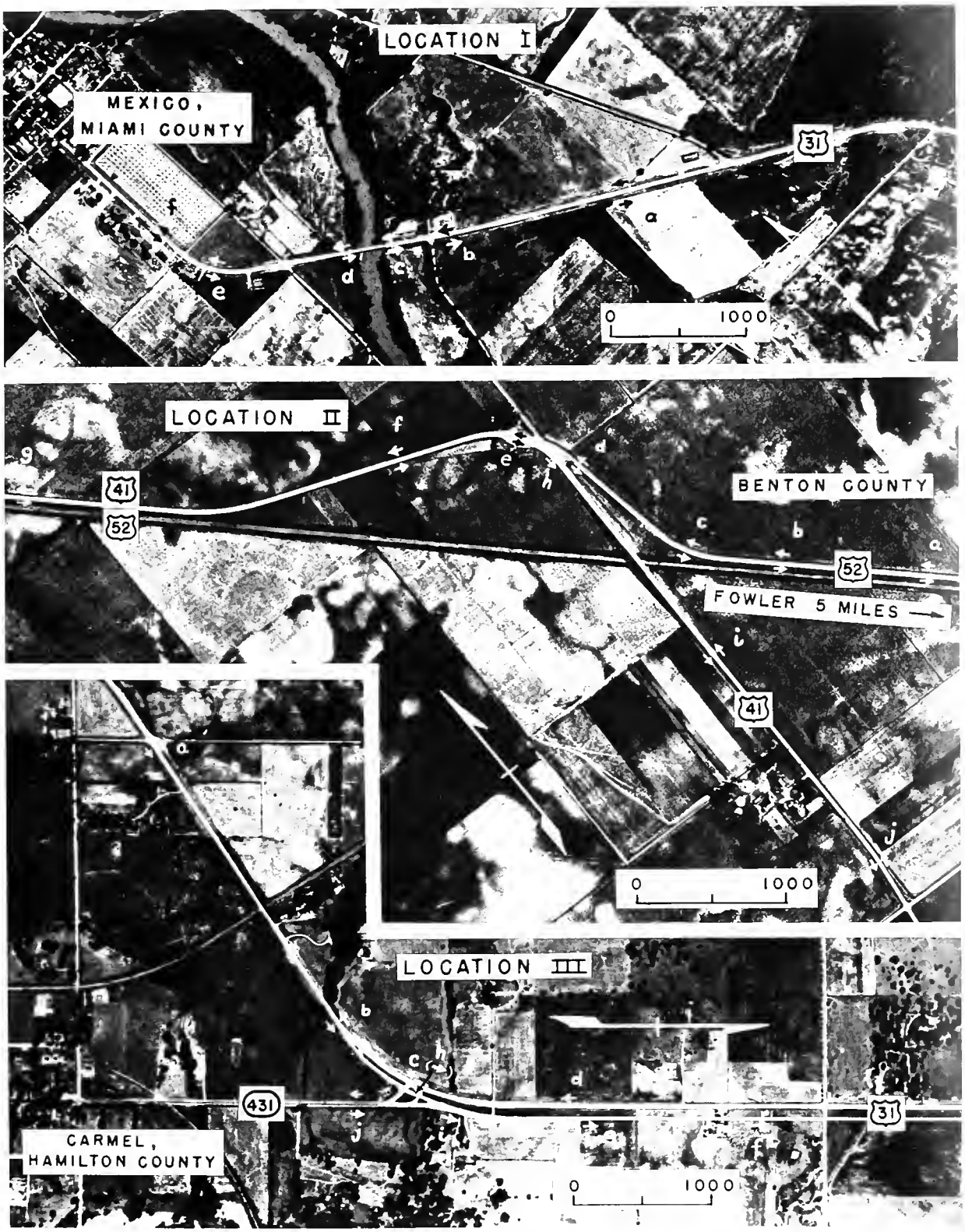
For the purposes of this study a very general definition of "delineation" was used. In addition to roadside reflectors (delineators), pavement edge lines, no passing lines, traffic signs and, at one location, channelizing islands, i.e., all traffic control devices which would help channelize or inform the driver so that he would be better able to choose a safe speed, were classed under the heading of delineation.

In subsequent discussions the term "delineator" will be reserved for references to roadside reflectors while "delineation" will be used as a generic term for all those devices mentioned in the previous paragraph.



STUDY LOCATIONS

FIGURE 1



STUDY LOCATIONS SHOWING
SPEED MEASUREMENT STATIONS

PLATE I

PREVIOUS INVESTIGATIONS

Delineation, in the sense in which we have defined it, is not a new innovation. It is a further step in the development of aids to night visibility which had previously been limited to such devices as reflector buttons and painting for the purpose of marking trees, posts, rocks, pillars, and other obstructions in or near the roadway. The distant lamps on an illuminated thoroughfare may serve the same purpose as delineators by indicating the alignment of the roadway ahead.

In 1944, the Bureau of Public Roads conducted a limited study of two-lane tangent sections in New Jersey which indicated little change in night driving speed between lighted and unlighted sections(9).

Roadside reflectors for the purpose of delineating the course of the roadway were introduced by the State of Michigan in 1938(5)(6). Delineators were installed along two major trunk routes and the effect on numbers and types of accidents was studied. The Highway Research Board Committee on Night Visibility, reporting on a four-year before and after study of these two installations, stated that "Results showed that 'the special hazards of nighttime driving were reduced 20 to 25 percent after the installation of delineators.'"(11)

Quimby in 1948 performed a study, while at Purdue University, on the effect of various types of signs and reflectorization on vehicle speed and lateral placement at the approach to a narrow bridge(10). He found that night speeds and placement were affected by the type of sign or reflector used. Day speeds and placement, however, were relatively unaffected, regardless of the signing installation, indicating that the driver was at all times primarily influenced by the bridge itself.

Painted edge of pavement lines are a more recent development in delineation forms. Several recent studies have been performed with regard to edge lines. Most of these, however, have dealt either wholly or primarily with their effect on lateral placement.

The State of Connecticut began tests using edge lines on a four-mile stretch of the Merritt Parkway in 1953(8). Results of data recorded at six stations showed an improvement in the distribution of both speed and lateral placement. Use of the edge lines produced a more uniform speed pattern, daytime speeds being decreased while nighttime speeds increased. One typical station reported a decrease in the daytime pace from 51-61 miles per hour to 50-60, while the nighttime pace increased from 47-57 to 49-59.

In 1956 and 1957, the Louisiana Department of Highways with the Bureau of Public Roads conducted tests on the effects of various types of edge lines on speed and placement(12). Edge lines were found to have no effect on speeds, but it was reported that vehicles tended to move closer to the centerline at higher speeds. Average placement was slightly nearer the centerline at night when a continuous line was in place, but a dashed line seemed to have no effect on placement at any time. It is not known, however, whether these results have any statistical significance. A study of accidents for a six-month period before and six months after striping showed no improvement in accident experience.

At the same time that the Merritt Parkway tests in Connecticut were being conducted, New York's Westchester County painted right shoulder lines on a particularly dangerous 3 1/2 mile stretch of the

Hutchinson River Parkway which joins the Merritt Parkway at the state line(8). A drop in the accident rate from 40 in the five-month period preceding striping to 14 in the subsequent five-month period was reported.

A somewhat different type of edge line was placed on a 15-mile test section of U. S. 89 in Arizona(13). This highway consisted of 12 foot lanes and 8 foot shoulders, both asphalt-paved with no distinction in color or texture——in effect, a two-lane highway with 20 foot lanes. A dashed shoulder stripe was placed at the outer edge of the shoulder in an effort to decrease the accident rate, particularly those accidents involving vehicles running off the shoulder or crossing the centerline. A tabulation of accidents for the period March - October, 1954 showed a 3-1 ratio of accident occurrence for non-striped sections to those striped.

As far as is known, this study is the first attempt to concentrate on the relation between delineation and speed.

SCOPE

Limits of Study

Some difficulty was involved in choosing the locations at which the study was to be performed. Study sites had to be within a reasonable distance of Lafayette, carry sufficient traffic so as to expedite the collection of data, and be of such a nature as to probably show the effects of delineation under field conditions, i.e., exhibit characteristics that warranted special treatment.

Assistance in this quest was provided by the State Highway Department, which was then contemplating the installation of illumination at various locations throughout the state. Three of these locations were found to meet the requirements given above. All three were within one and one-half hours driving time of Lafayette, on primary trunk routes, and special treatment was being proposed for them.

Furthermore, it was foreseen that a comprehensive study in the area of speed and visibility could be developed should any or all of the sites be lighted. Some of the speed measurement stations were, therefore, chosen with this in mind.

The types of vehicles under consideration were passenger cars and heavy commercial vehicles, each type being analyzed separately. From the preliminary survey, it was found that only at one location were commercial vehicles to be found in sufficient numbers for adequate sampling. Of these, the number of light trucks and buses was negligible, so that only heavy trucks (primarily semi-trailers) were recorded as commercial vehicles.

Only free-moving through vehicles were recorded, a free-moving vehicle having been defined for the purposes of this study as one whose speed was not being affected by the immediate presence of other vehicles in its path. In accordance with this definition, only the lead vehicle in a platoon was recorded. The minimum allowable headway for recording was about five seconds. Vehicles in the act of passing, or initiating or completing a pass were not recorded. Vehicles which had turned onto the roadway prior to passing a station or which turned off the roadway after passing a station were not recorded, provided that such turns were deemed to have affected the speed of the vehicle and also provided that such turning movements could be observed by the recorder.

The major variable under investigation was visibility. Accordingly, speeds were measured under three conditions: during daylight hours, at night with the existing delineation, and again at night after additional delineation had been installed.

In order to further reduce the number of variables, data were collected on week days only and, as far as possible, at the same times each day. Data collection took place only when the pavement was dry and optimum atmospheric conditions (i.e., absence of fog or haze) were present.

Because of the distances of the sites from Lafayette, the daytime and nighttime before phases of the study were conducted on the same days. Measurements were begun in the late afternoon; data collection ceased not later than one hour before sunset and was resumed when darkness fell.

The before study was conducted during the months of July and August, 1958. After the installation of additional delineation, data for the after study were collected in September and October, 1958.

Speed Measurement Stations

Before the final sites had been selected, a general plan for speed measurement stations had been envisioned, which plan was to have been enacted along each avenue of through movement. Part of this plan called for a station relatively far removed from the immediate site on each leg leading to the site. The purpose of these stations was to permit the obtaining of data on normal or open highway speeds of vehicles approaching and leaving the sites. Other stations were to be located in the approach and recovery zones on either side of the site. Finally, one or more stations were to be located at the entrance, exit or center of the particular feature (e.g., intersection) involved. These were defined as "critical" stations.

This plan, with modifications according to the particular features found at each location, was put into practice for the study. In consideration of a possible future illumination study, the stations in the approach and recovery zones were situated so as to coincide with the entrances to and exits from the lighted sections. One further consideration in the choice of station location was the opportunity for concealment of the observer.

Aerial views of the three locations showing the speed measurement stations are shown in Plate I.

Locations

As was mentioned previously, each of the locations is distinctive. Each is of a different type, and two of them are rather unusual for their type. The narrow bridge at location I is unusually long and narrow. The intersection at location II is a particularly hazardous one, the two roadways merging on a curve and at a very small angle. The other intersection, at location III, is also on a curve and also has roads merging at a small angle, but it is of more modern design.

Location I (see Figure 5 and Plate II) is on U. S. 31, south of Mexico and north of Peru in Miami County. The area under study consisted of the approaches to the Eel River bridge and the curve north of the bridge. The hazard created by the bridge stems from the fact that it is 256 feet in length and narrower than the roadway adjacent to it. The roadway in the vicinity of the bridge is 22 feet wide, whereas the usable pavement width on the bridge is 19 feet 2 inches. Formidable looking steel trusses on either side give a greater appearance of narrowness.

Northbound drivers on U. S. 31 encounter a series of curves marked with advisory speeds between Peru and the bridge. Many of them may attempt to "make up for lost time" on the long tangent preceding the bridge. An oversize "narrow bridge - 30 mph" sign is located on the approach to the bridge but may be largely ignored, particularly since direct view of the bridge entrance is partially obscured by a slight curve in the road. The result is rapid deceleration at the bridge or dangerously high speeds across the bridge. Leading away from the bridge, to the north, is a plus five percent grade at the crest of which is a sharp horizontal curve.

That this is a hazardous location can be verified from the accident record shown in Figure 2. Further study of the accident record at this location resulted in information which may be indicative of the role of delineation in speed control and safety. Early in 1957, six delineators were placed on the curve north of the bridge. Five accidents had occurred at this curve in the year 1956, all stemming from excessive speed and consequent failure to negotiate the curve. From the time of installation of the delineators early in 1957 until August 1958, only one accident had occurred at this curve.

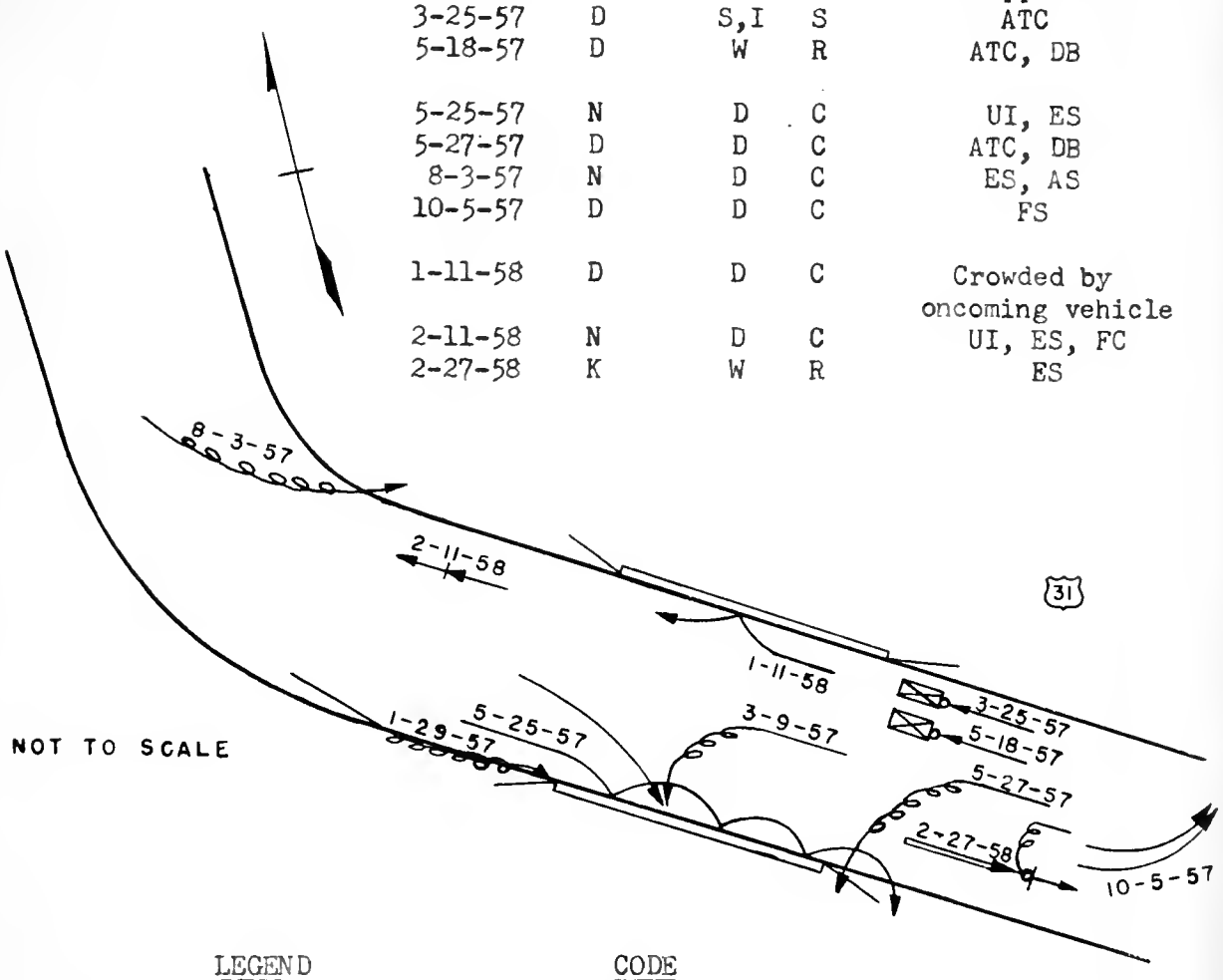
Location II (see Figure 6 and Plates III and IV) is the vicinity of the southern junction of routes U. S. 41 and U. S. 52, north of Fowler in Benton County. Travel through this section is complicated by the presence of sharp curves to the north and to the south of the intersection. The intersection itself is on a sharp curve. Further hazard arises from the fact that the two roadways merge at a very small angle, so that the width of paved area at the point where the two roadways join is about 100 feet. Sight distance from either end of the intersection curve is poor because of a high berm and narrow shoulder on the inside of the curve. Complicating matters further is the presence of a service station and truck stop abutting the intersection curve with parking areas along both sides of the roadway. Some roadway illumination is provided by light from the service station.

Immediately prior to the intersection, on U. S. 41, is a crest vertical curve with five percent grades. Vehicles from U. S. 41 are required to stop at the junction, but the expanse of pavement that existed prior to the construction of channelizing islands caused confusion as to where the stop should be made and many of them encroached

ACCIDENT RECORD
LOCATION I

PERIOD: 1-1-57 TO 9-1-58

DATE	TIME OF DAY	PVMT	WEATHER	MODIFYING CIRCUMSTANCES
1-29-57	N	S,I	S	AS
3-9-57	N	D	C	Unknown vehicle stopped ahead
3-25-57	D	S,I	S	ATC
5-18-57	D	W	R	ATC, DB
5-25-57	N	D	C	UI, ES
5-27-57	D	D	C	ATC, DB
8-3-57	N	D	C	ES, AS
10-5-57	D	D	C	FS
1-11-58	D	D	C	Crowded by oncoming vehicle
2-11-58	N	D	C	UI, ES, FC
2-27-58	K	W	R	ES



LEGEND

- Moving vehicle
- Parked or stopped vehicle
- Tractor trailer
- Right angle collision
- Rear end collision
- Side swipe
- Out of control or skid
- Fatal
- Personal injury
- Property damage only

CODE

PVMT: D-Dry, W-Wet, S-Snow, I-Ice

WEATHER: C-Clear, R-Rain, S-Snow, F-Fog

TIME OF DAY: D-Day, N-Night, K-Dusk

MODIFYING CIRCUMSTANCES

UI: Under influence
WS: Wrong side(not passing)
ES: Excessive speed
FC: Following too closely
FYR: Failure to yield right of way
FS: Failure to signal
DB: Defective brakes
AS: Asleep
RD: Reckless driving
ATC: Allow traffic to clear bridge

FIGURE 2

on the through lane. Drivers approaching the junction from the north on U. S. 52 found difficulty in reaching their intended route; this resulted in many vehicles either stopping in the intersection or attempting U-turns on the legs after the intersection.

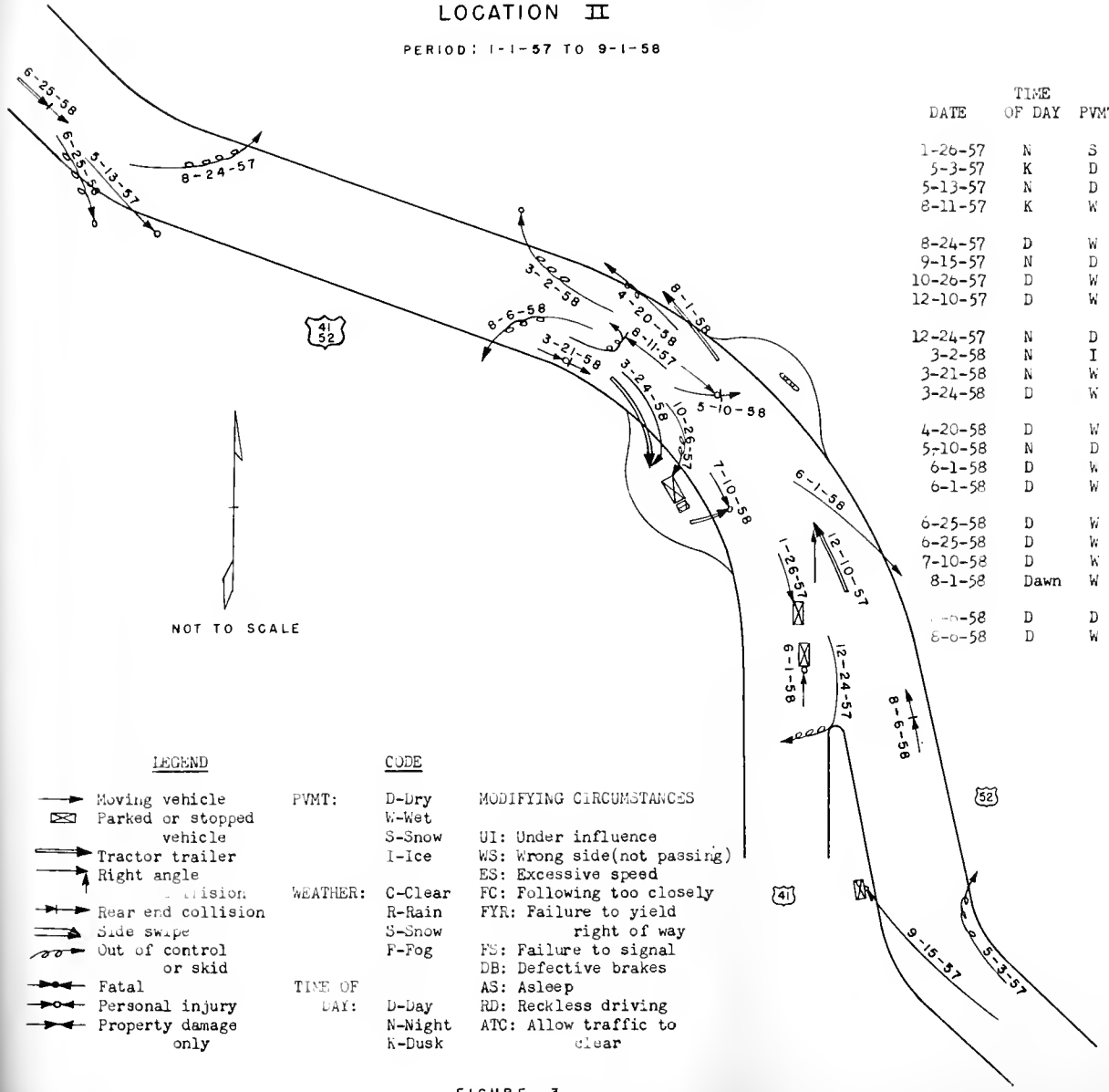
Figure 3 shows the extremely poor accident record for this location. Note that a large proportion of the accidents occurred at the northern end of the intersection curve where the pavement begins to resume its normal width. Furthermore, almost three-fourths of all the accidents occurred under slippery pavement conditions. These data would seem to indicate that excessive speed for conditions played a major part in accident causation at this location.

Location III (see Figure 7 and Plates V and VI) is the vicinity of the junction of U. S. 31 and S. R. 431 north of Carmel in Hamilton County. U. S. 31 is a dual lane highway at this point; however, the transition to a two-lane highway occurs about 800 feet southwest of the intersection. The intersection had recently been rebuilt to modern standards, all turning movements having been channelized and a merging lane having been provided for traffic from S. R. 431. Though the intersection is on a curve, the curvature is in the order of three and four degrees for the southbound and northbound through lanes, respectively, and sight distances are adequate. Some illumination is provided by lights from a service station and a restaurant located on either side of the intersection.

Included as part of the study area was a part of the two-lane section of U. S. 31 encompassing a crest vertical curve just past the transition section. One station was located on the grade near the transition and another beyond the railroad overpass at the end of the

ACCIDENT RECORD
LOCATION II

PERIOD: 1-1-57 TO 9-1-58



DATE	TIME OF DAY	PVMT	WEATHER	MODIFYING CIRCUMSTANCES
1-26-57	N	S	S	WS, UI
5-3-57	K	D	C	ES
5-13-57	N	D	C	ES or AS
8-11-57	K	W	C	
8-24-57	D	W	R	
9-15-57	N	D	C	WS
10-26-57	D	W	S	Blowout
12-10-57	D	W	C	FYR
12-24-57	N	D	C	ES
3-2-58	N	I	S	Light weight car
3-21-58	N	W	C	RD
3-24-58	D	W	R	FS
4-20-58	D	W	R	Inexperienced driver
5-10-58	N	D	C	UI, WS
6-1-58	D	W	C	RD
6-1-58	D	W	R	FYR by unknown car from U. S. 41
6-25-58	D	W	R	ES
6-25-58	D	W	R	RD
7-10-58	D	W	R	FYR
8-1-58	Dawn	W	F	
[illegible]-58	D	D	C	FC
8-6-58	D	W	R	ES

LEGEND

- Moving vehicle
- Parked or stopped vehicle
- Tractor trailer
- Right angle collision
- Rear end collision
- Side swipe
- Out of control or skid
- Fatal
- Personal injury
- Property damage only

CODE

PVMT:
D-Dry
W-Wet
S-Snow
I-Ice

WEATHER:
C-Clear
R-Rain
S-Snow
F-Fog

TIME OF DAY:
D-Day
N-Night
K-Dusk

MODIFYING CIRCUMSTANCES

UI: Under influence
WS: Wrong side(not passing)
ES: Excessive speed
FC: Following too closely
FYR: Failure to yield right of way
FS: Failure to signal
DB: Defective brakes
AS: Asleep
RD: Reckless driving
ATC: Allow traffic to clear

FIGURE 3

tangent leading away from the vertical curve.

The accident record for this location is shown in Figure 4.

Improvements

Since this study was concerned with the effect of added delineation under field conditions, the extent to which each location was delineated for the after study was purposely limited to the specific requirements of the location. In other words, additional delineation was not installed for its own sake, but rather, only where it was felt that it would produce a desirable effect. Excessive use might only have served to diminish the value of delineation. Some consideration also had to be given to the availability of materials.

Improvements at location I (see Figure 5) consisted of the placement of additional delineators on the curve so as to achieve approximately a 30-foot spacing, and the placement of white edge lines on both sides of the pavement. These edge lines were continuous through the location and extended from well back of the south approach to the bridge to well beyond the curve. A single yellow line was placed along the bridge centerline, and the bridge curbs were painted yellow. The existing no-passing barrier lines were extended on both approaches to the bridge.

An extension of the speed zone to include the bridge was at first contemplated, but this was later rejected on the grounds that such a procedure did not come under the heading of delineation and would have obscured any effects on speed due to the delineation installed.

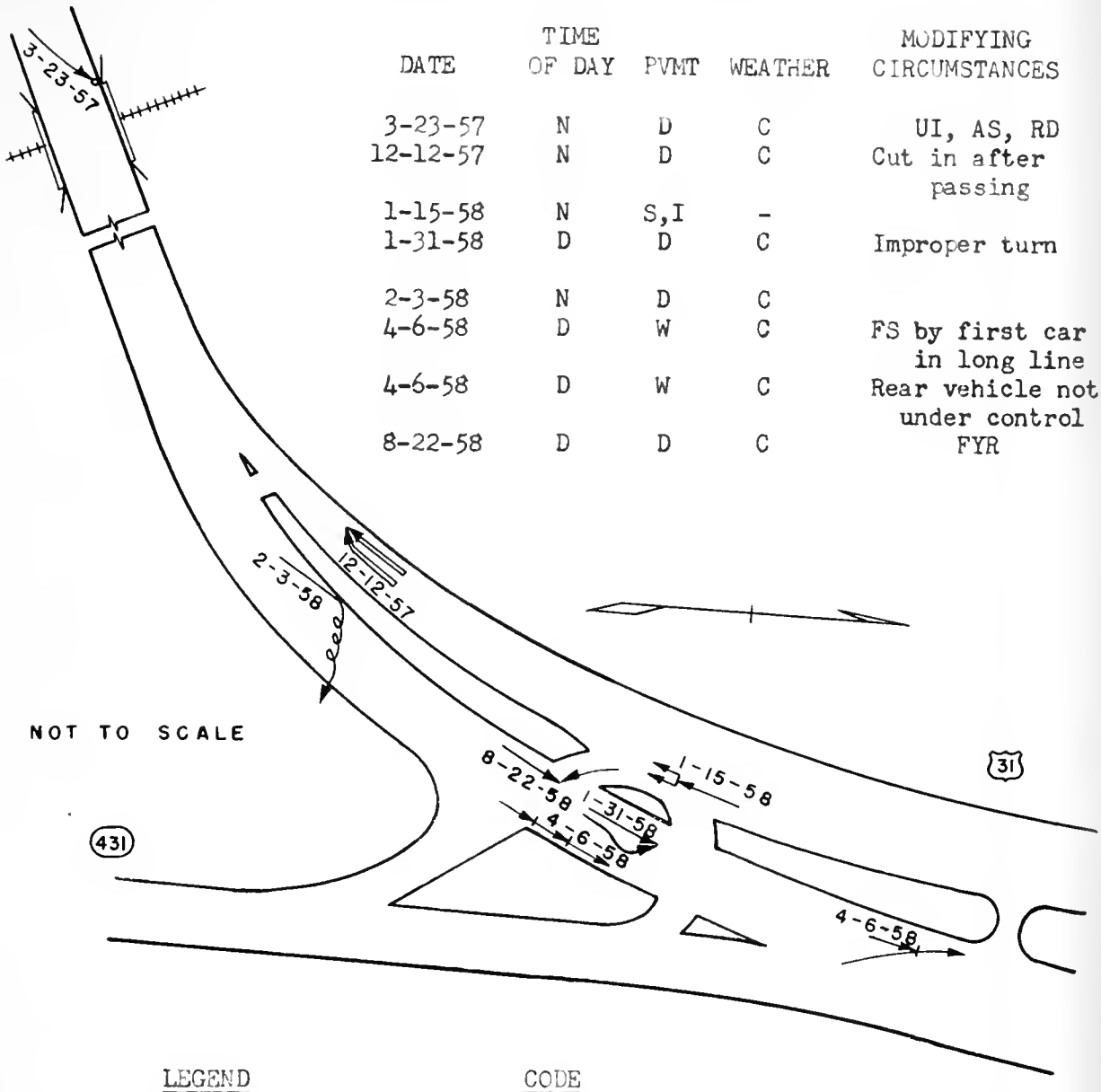
State Highway Department plans for re-signing and channelizing the intersection at location II had been in progress at the

ACCIDENT RECORD

LOCATION III

PERIOD: 1-1-57 TO 9-1-58

DATE	TIME OF DAY	PVMT	WEATHER	MODIFYING CIRCUMSTANCES
3-23-57	N	D	C	UI, AS, RD
12-12-57	N	D	C	Cut in after passing
1-15-58	N	S,I	-	
1-31-58	D	D	C	Improper turn
2-3-58	N	D	C	
4-6-58	D	W	C	FS by first car in long line
4-6-58	D	W	C	Rear vehicle not under control
8-22-58	D	D	C	FYR



LEGEND

- Moving vehicle
- Parked or stopped vehicle
- Tractor trailer
- Right angle collision
- Rear end collision
- Side swipe
- Out of control or skid
- Fatal
- Personal injury
- Property damage only

CODE

PVMT: D-Dry, W-Wet, S-Snow, I-Ice

WEATHER: C-Clear, R-Rain, S-Snow, F-Fog

TIME OF DAY: D-Day, N-Night, K-Dusk

MODIFYING CIRCUMSTANCES

UI: Under influence
WS: Wrong side(not passing)
ES: Excessive speed
FC: Following too closely
FYR: Failure to yield right of way
FS: Failure to signal
DB: Defective brakes
AS: Asleep
RD: Reckless driving
ATC: Allow traffic to clear

FIGURE 4

DELINEATION

LOCATION I

BEFORE

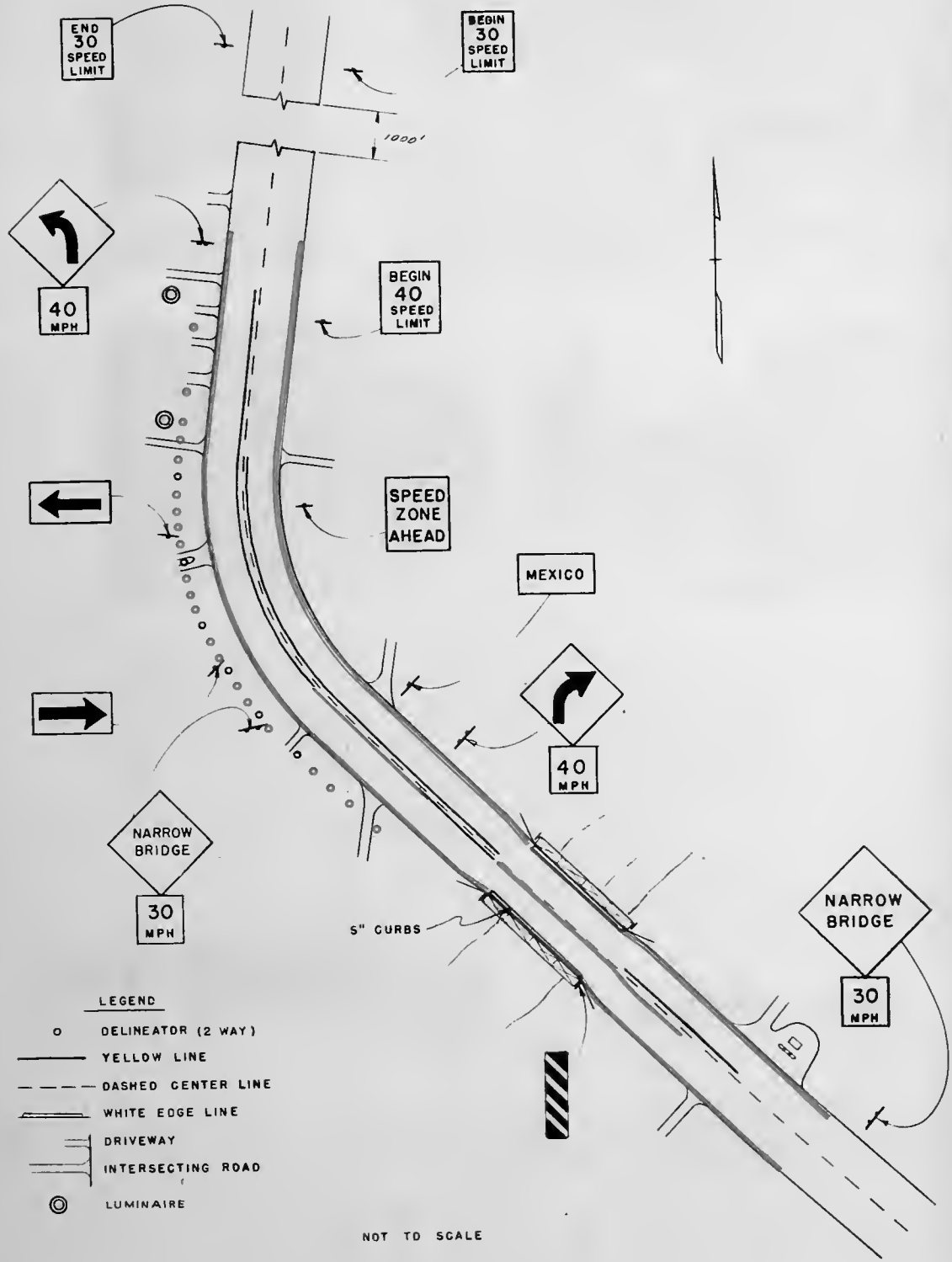


FIGURE 5

DELINEATION

LOCATION I

BEFORE

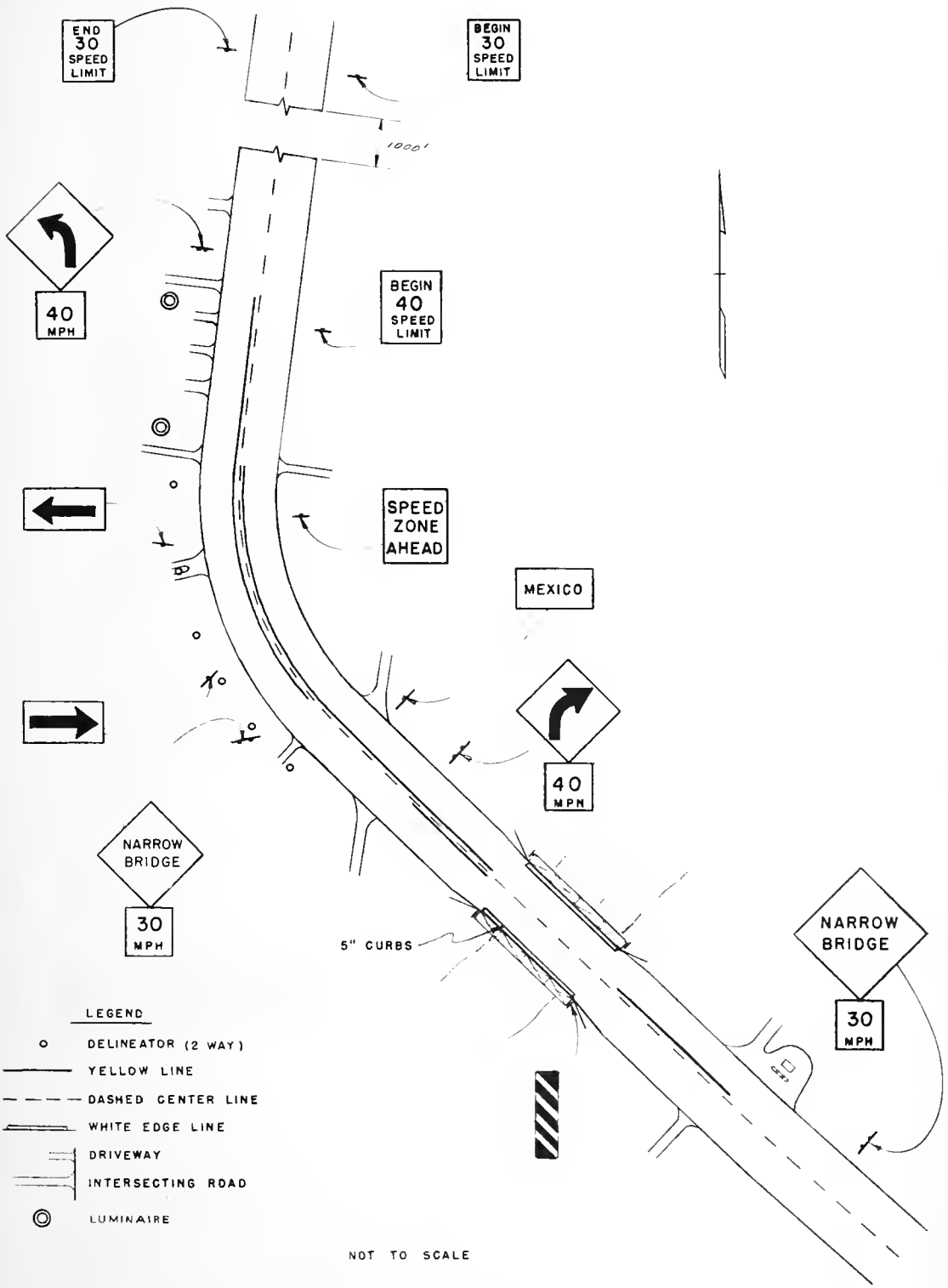


FIGURE 5

Entrance to bridge from south.

Approach to bridge from south.

South end of curve. Left: looking south (bridge in background).
Right: looking north.

VIEWS AT LOCATION I

PLATE II

time that delineation plans were being prepared. The final plan of improvement was, therefore, an amalgamation of both these plans. The plan as installed included at least two items which do not follow recommended practice. These consisted of the placement of advisory speed signs in conjunction with a route designation sign and "stop ahead" signs. These speed signs were installed by the State Highway Department and were in place for the study. Such installation is not recommended or even suggested by this study.

The channelizing islands were designed to break up the existing expanse of pavement at the junction. Their purpose was to channelize southbound vehicles into their desired paths and indicate the proper stopping point for vehicles from U. S. 41. Temporary islands outlined with sandbags coated with reflective paint were in place for the study.

Delineators were placed on the north and south curves, on both sides of the tangent between the south curve and the junction, and, where possible, on both sides of the intersection curve. White posts were placed along the outside of the parking area on the intersection curve, far enough back from the pavement to provide adequate shoulder space. These posts served both as delineators and as a barrier to prevent access to this area*. Edge lines were laid continuously through the study area, encompassing the north, intersection, and south curves on U. S. 52, and extending beyond the vertical curve on U. S. 41.

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*Plate III shows delineators, made up of reflective panels mounted on metal posts, in place at the parking area. These had been replaced before data collection for the after study was begun.

40
M.P.H.

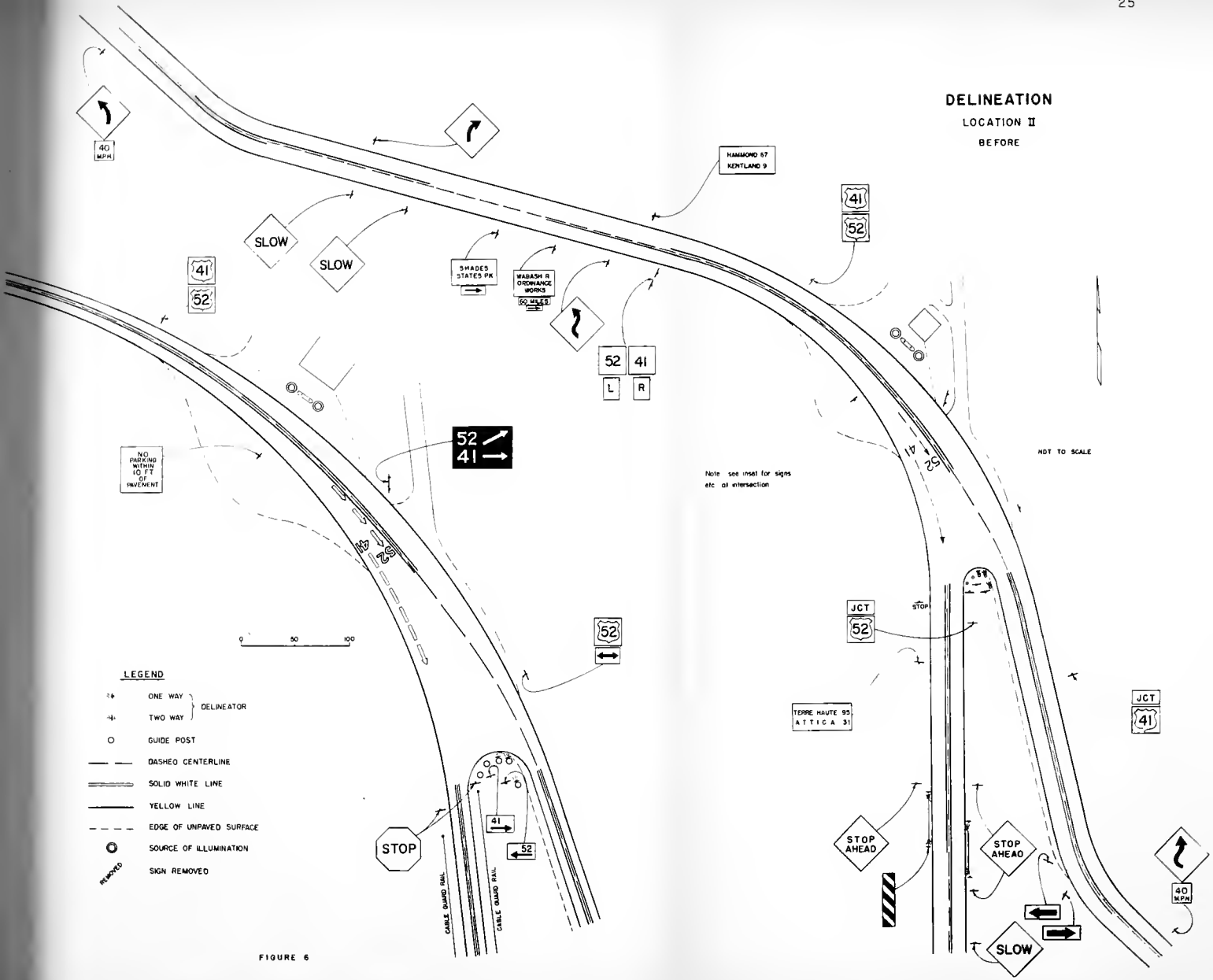
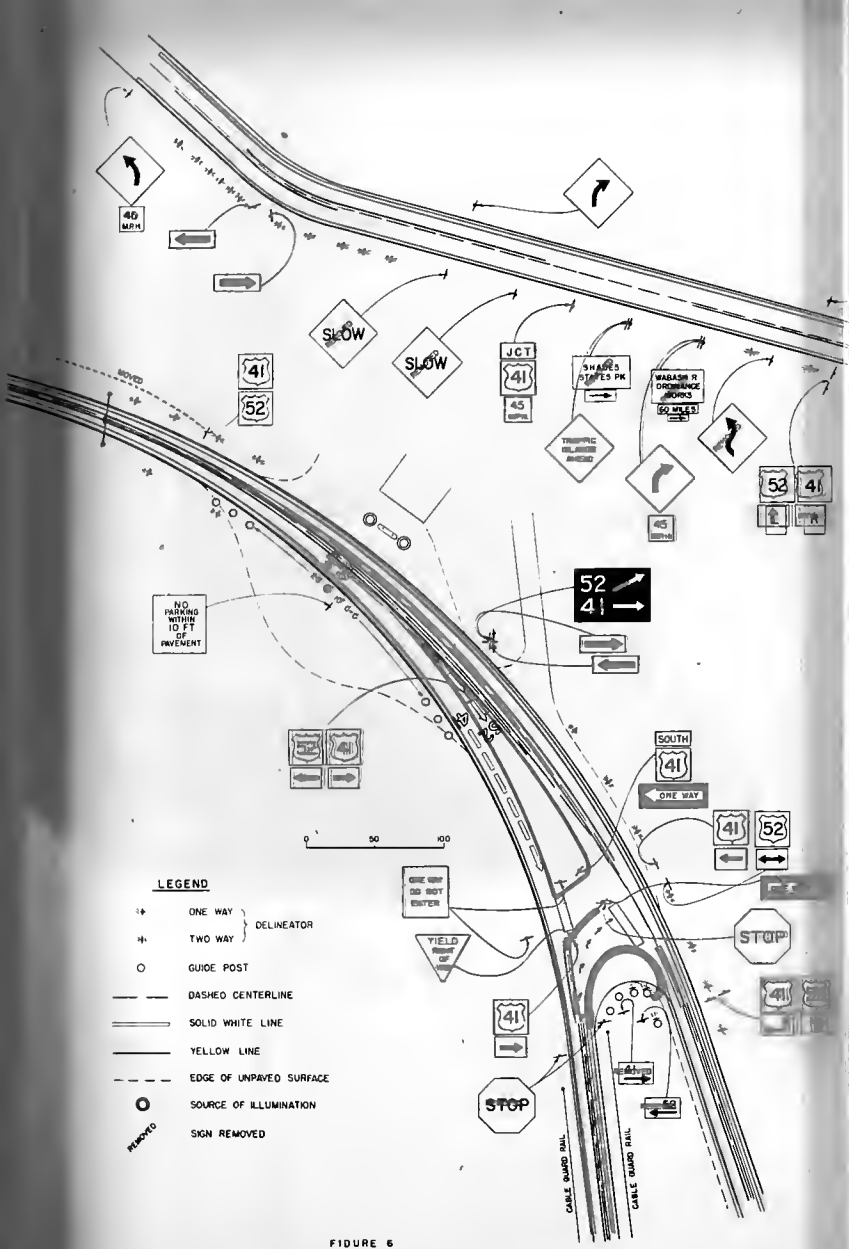

DELINEATION
LOCATION II
BEFORE
NOT TO SCALE
Note see inset for signs etc at intersection
40 M.P.H.
SLOW
SLOW
41
52
SHADES STATES PK
WABASH R ORDNANCE WORKS
HAMMOND 67
KENTLAND 9
52
41
L
R
NO PARKING WITHIN 10 FT OF PAVEMENT
52
41
STOP
41
52
CABLE GUARD RAIL
CABLE GUARD RAIL
JCT
52
STOP
TERRE HAUTE 95
ATTICA 31
JCT
41
STOP AHEAD
STOP AHEAD
SLOW
40 M.P.H.
0
50
100
LEGEND
ONE WAY
TWO WAY
DELINEATOR
GUIDE POST
DASHED CENTERLINE
SOLID WHITE LINE
YELLOW LINE
EDGE OF UNPAVED SURFACE
SOURCE OF ILLUMINATION
REMOVED
SIGN REMOVED

FIGURE 6

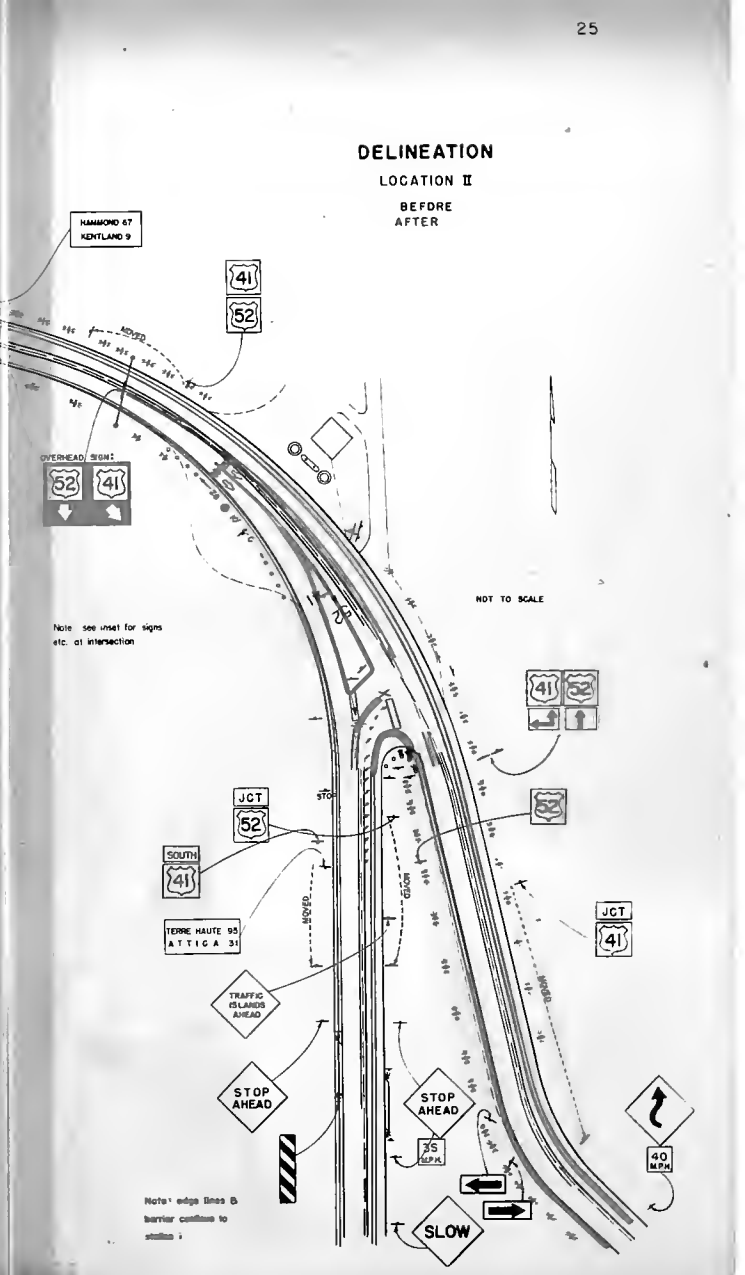


FIDURE 6

DELINEATION

LOCATION II

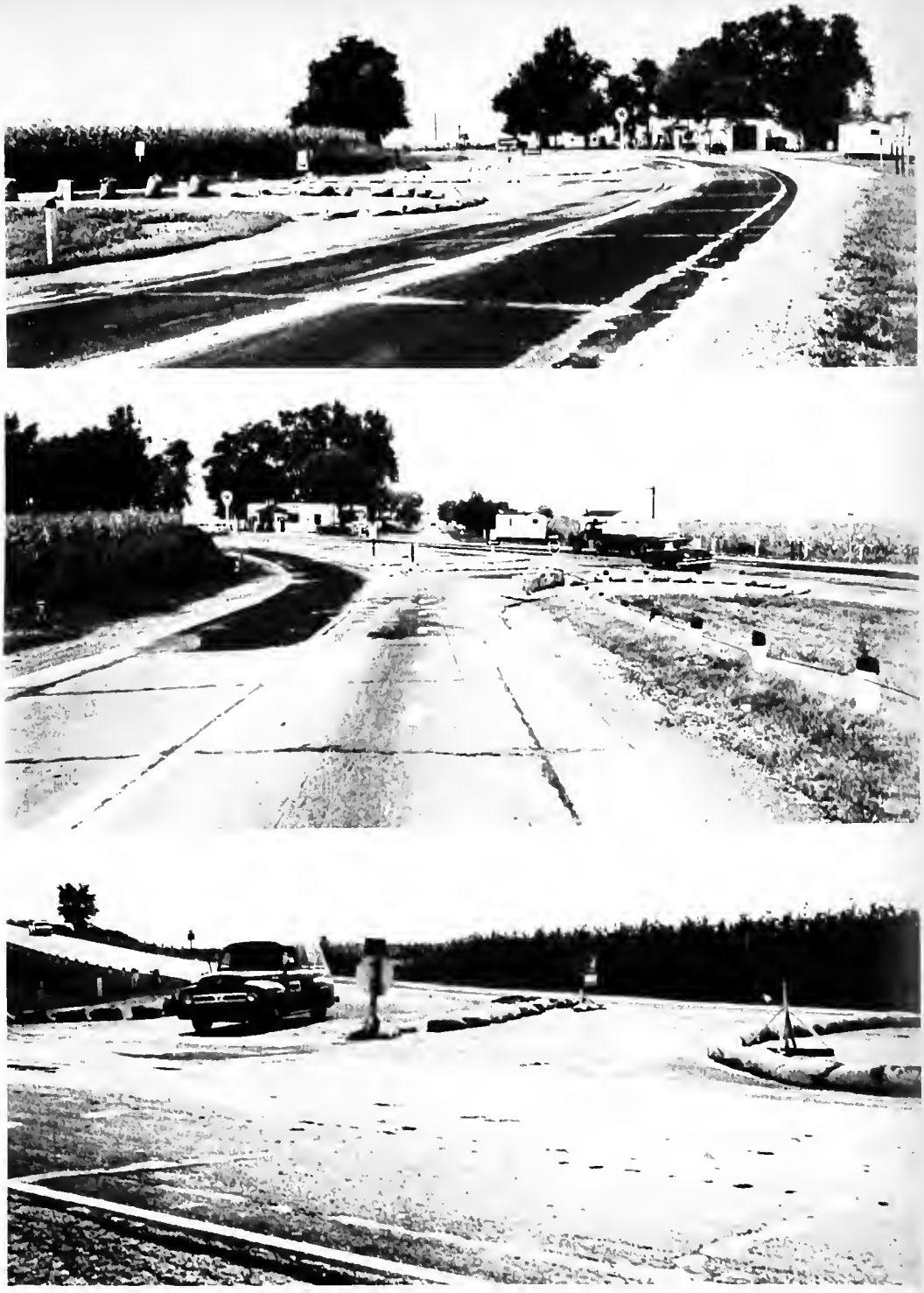
BEFORE
AFTER



Top: Overhead sign prior to island, looking south.
Center: Nose of diverging island, looking south.
Bottom: South curve U.S. 52, looking south.

VIEWS AT LOCATION II

PLATE III



Top: Entrance to intersection from U.S. 52, looking north.
Center: Entrance to intersection from U. S. 41, looking north.
Bottom: Turning channels. Vehicle from U.S. 41, stopped for turn.

VIEWS AT LOCATION II

PLATE IV

Directional and guide signing was improved; an overhead sign was constructed north of the dividing island, and extraneous signs were removed.

Figure 6 shows the before and after delineation at location II.

Since the signing layout at location III was found to be adequate, the major improvements consisted of the addition of delineators and edge lines only. One way delineators were installed to the right of each roadway from the crest of the vertical curve on U. S. 31, through the intersection to beyond the end of the merging lane taper from S. R. 431. Existing guide posts were fitted with reflectors to serve as delineators. Edge lines were painted on both sides of each roadway from station a to beyond the merging lane taper on U. S. 31, and to station j on S. R. 431. These edge lines were continuous through the location except for being broken at the channel mouths. A painted white line was installed to separate the merging lane from the U. S. 31 traffic lane to prevent its being used by vehicles on U. S. 31. It had been intended that this line terminate prior to the beginning of the merging lane taper but inadvertently it was continued to the end of the taper. It is recommended that this be corrected in future repaintings.

See Figure 7 for before and after delineation at location III.

Note: e
lines co
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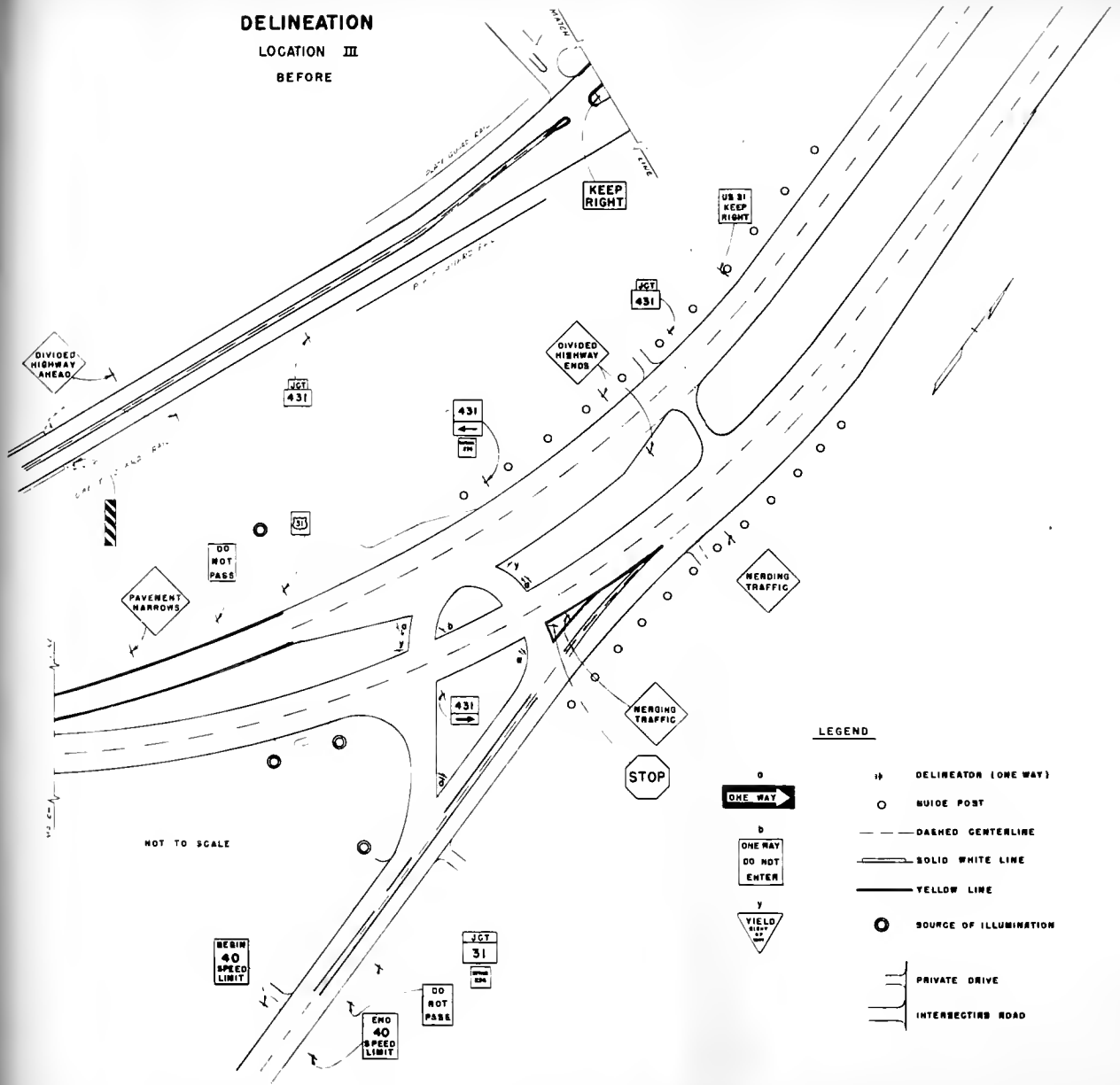
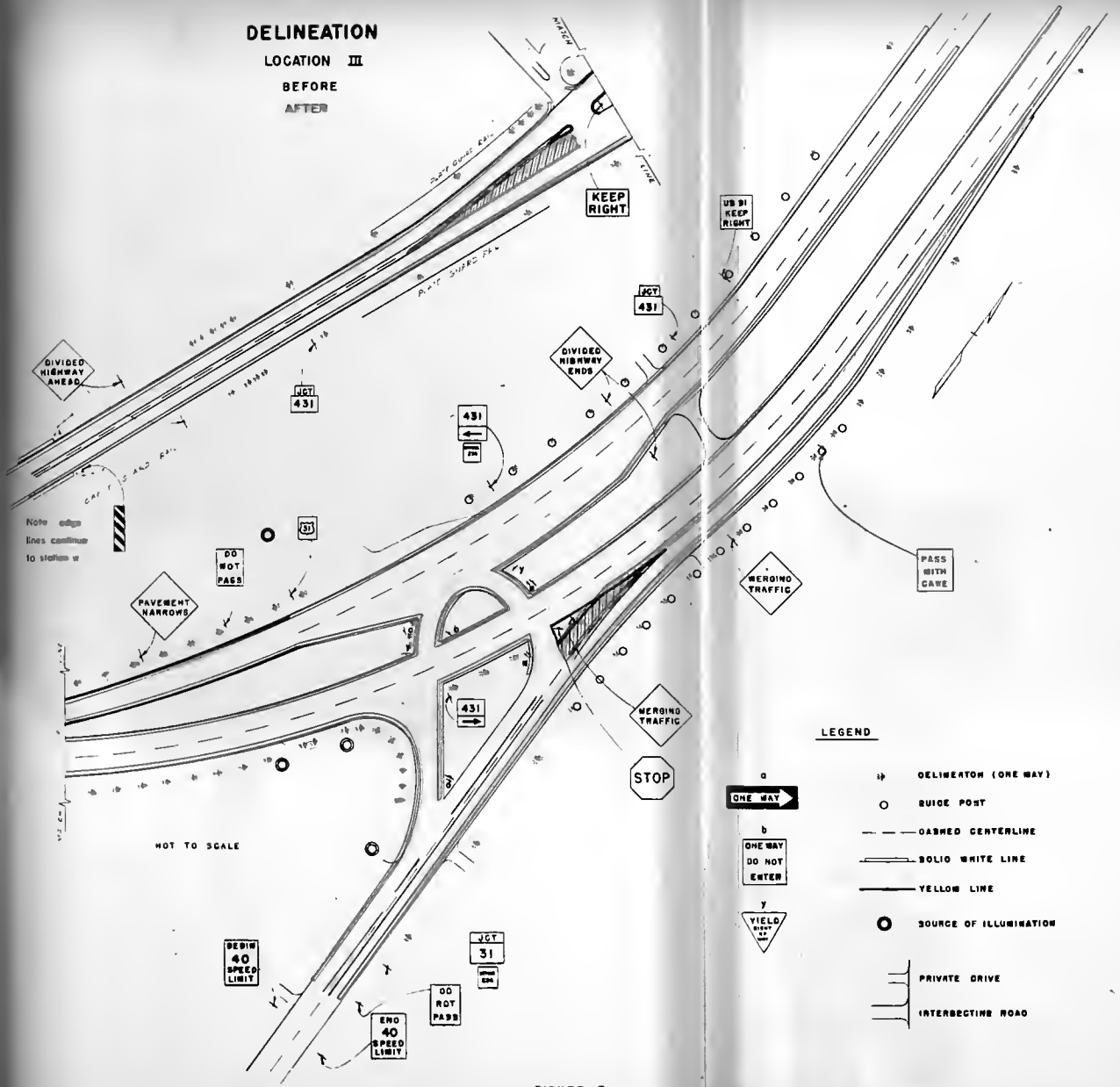
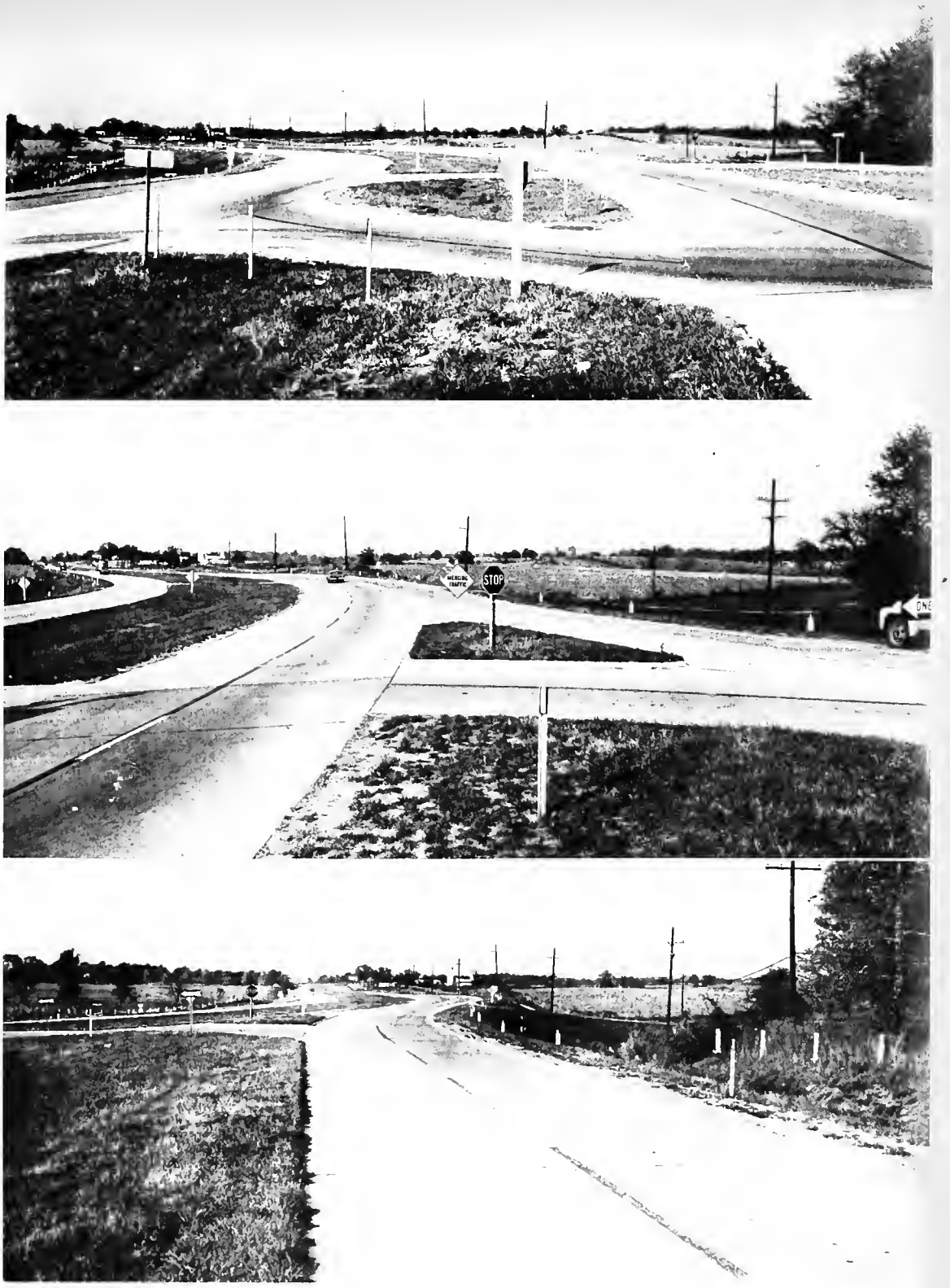

DELINEATION
LOCATION III
BEFORE
KEEP RIGHT
US 31 KEEP RIGHT
JCT 431
DIVIDED HIGHWAY AHEAD
DIVIDED HIGHWAY ENDS
431
DO NOT PASS
PAVEMENT NARROWS
MERGING TRAFFIC
MERGING TRAFFIC
STOP
NOT TO SCALE
BEGIN 40 SPEED LIMIT
JCT 31
DO NOT PASS
END 40 SPEED LIMIT
LEGEND
ONE WAY
ONE WAY DO NOT ENTER
YIELD
DELINEATOR (ONE WAY)
GUIDE POST
DASHED CENTERLINE
SOLID WHITE LINE
YELLOW LINE
SOURCE OF ILLUMINATION
PRIVATE DRIVE
INTERSECTING ROAD

FIGURE 7


DELINEATION
LOCATION III
BEFORE
AFTER
KEEP RIGHT
US 91 KEEP RIGHT
JCT 431
DIVIDED HIGHWAY AHEAD
DIVIDED HIGHWAY ENDS
431
DO NOT PASS
PAVEMENT NARROWS
MERGING TRAFFIC
PASS WITH CARE
STOP
BEGIN 40 SPEED LIMIT
END 40 SPEED LIMIT
JCT 31
NOT TO SCALE
LEGEND
a
ONE WAY
b
ONE WAY DO NOT ENTER
y
YIELD
DELINEATION (ONE WAY)
GUIDE POST
DASHED CENTERLINE
SOLID WHITE LINE
YELLOW LINE
SOURCE OF ILLUMINATION
PRIVATE DRIVE
INTERSECTING ROAD

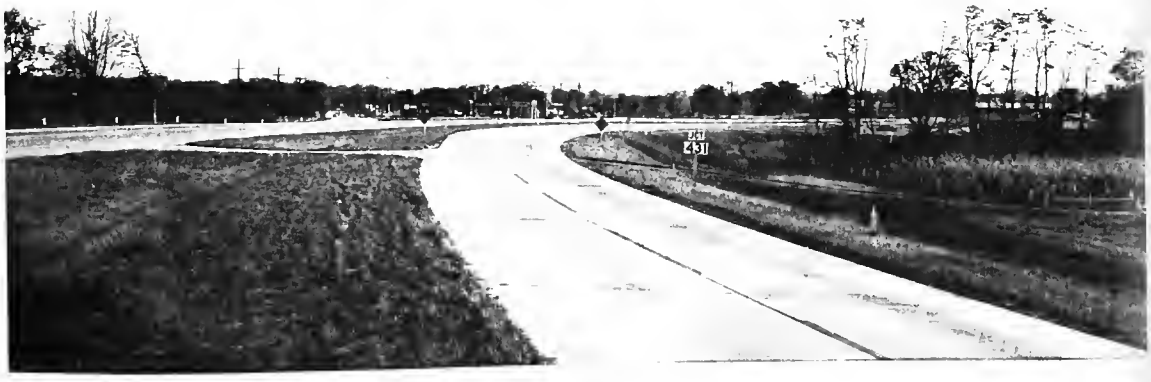
FIDURE 7



Top: Center of intersection, looking north. S.R. 431 in right background.
Center: Merging area, looking north on U.S. 31.
Bottom: Approach to merging area from S.R. 431.

VIEWS AT LOCATION III

PLATE V



Top: U.S. 31, transition, dual to two lane, looking southwest.
Center: Transition, looking northeast.
Bottom: U.S. 31, southbound approach to intersection.

VIEWS AT LOCATION III

PLATE VI

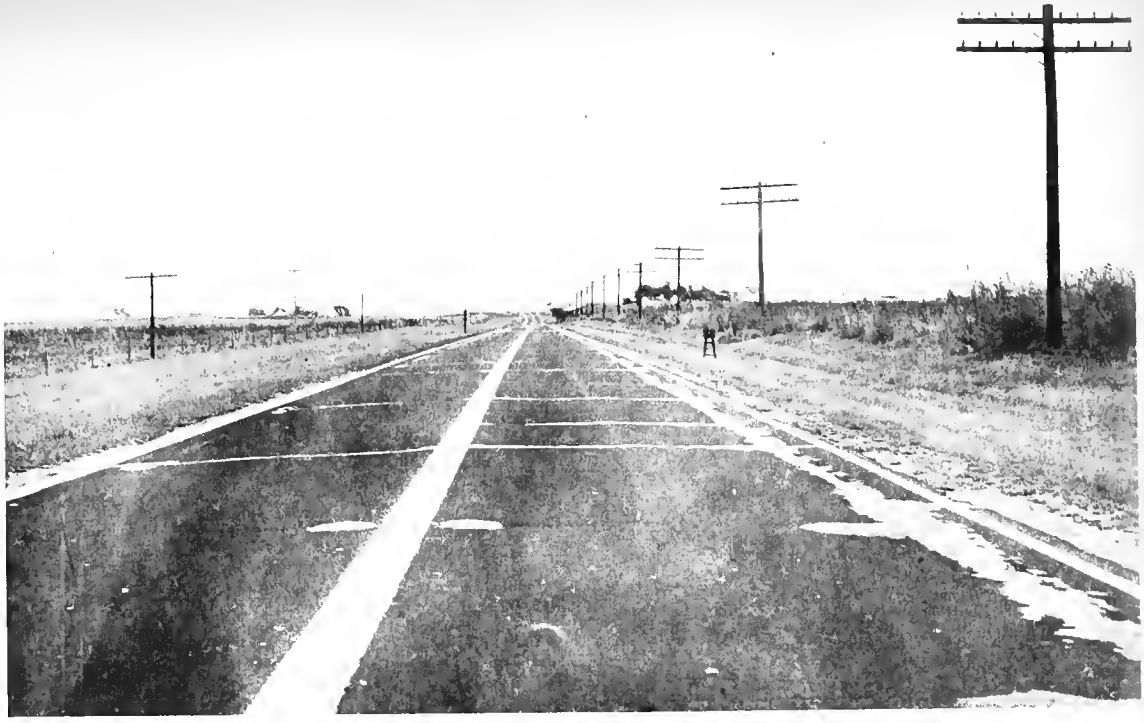
EQUIPMENT

All speed data for this study were obtained by the use of Electro-matic speed meters powered by automobile storage batteries. Two radar meters were in use at all times during the collection of data. One meter was borrowed from the State Highway Department; the other belongs to the Joint Highway Research Project. During the time when this meter was in use for another study, a second meter was borrowed from the State Highway Department.

The radar meter utilizes the Doppler effect to measure speeds. Radio waves of constant frequency are broadcast by the transmitter-receiver in a cone shaped beam 20 degrees wide. When reflected from a moving object these waves change frequency in proportion to the component of speed in the direction of the waves. The difference in frequency between the transmitted waves and the waves reflected back to the unit induces a potential that is read on the indicator, a voltmeter calibrated in equivalent miles per hour.

The effective range of the meter increases with its height above the roadway, the optimum height being about three feet. In order to achieve this height and facilitate aiming the units were supported on wooden stools which were levelled by means of stakes laid flat beneath the legs. (See Plate VII).

The meter registers the speeds of vehicles in the beam, travelling either toward or away from the unit, to an accuracy of one to two miles per hour. However, since the range of the beam for passenger cars is only about 100 to 150 feet, depending on the strength of the impulse, certain errors enter into the indicated reading.



Radar speedmeter as seen by driver in beam.

Radar speedmeter set up for observations. First car is within range for actuation.

RADAR SPEEDMETER

PLATE VII

It was necessary to set the meter back from the pavement edge in order to minimize any effect its presence might have on traffic approaching the station. The beam, therefore, had to be angled into the traffic stream. As a result, the indicator readings represented only a component of the true vehicle speed. Furthermore, passenger cars in the far lane would be within range only while intersecting the beam at a comparatively large angle. Individual meter calibration errors, amounting sometimes to two or three miles per hour, were often encountered.

Meter readings were also affected by the charge in the batteries. One day's operation was sufficient to discharge the batteries to the point where they would no longer be reliable. It was, therefore, necessary to recharge the batteries after each night's work. It was found convenient to alternate batteries, when extra ones were available, so that each battery would have the benefit of a full day's slow charge.

The impossibility of correcting all these errors individually was apparent from the beginning. A procedure for correcting the readings simultaneously for all errors was, therefore, incorporated into the data collection. The speedometer of the Purdue University vehicle used for transportation to the site was calibrated for indicated readings from 30 to 80 miles per hour at every ten mile per hour increment. This vehicle was used as a control car to calibrate each setup. Comparison of the "true" control car speeds with the corresponding meter readings yielded corrections for the rest of the data.

For the after phase of the study, a tuning fork was available for the calibration of the meter. This tuning fork vibrates at

a frequency equivalent to that which would register 60 miles per hour on the indicator. The calibration error for each setup could be obtained in this manner. However, the control car method still had to be used since there was no other way to correct for angular error.

PROCEDURE

Field

Before the actual collection of data was undertaken, preliminary surveys were made at each of the locations. Station locations were chosen, marked with stakes set flush with the ground and tied into existing landmarks. Scattered preliminary samples were taken, from which estimates were made of the range of standard deviations* to be encountered. This information was used in determining the sample sizes that would be required for statistical comparisons. (See Appendix A.)

It was found that better results could be obtained on curves where it was desired to record speeds in both directions if the meter was located on the inside of the curve rather than on the outside.

With two radar meters in operation simultaneously in the same vicinity it was necessary to have them as far removed from each other as possible in order to minimize the effect of a second setup on vehicles which had already passed one. Where possible, stations on different approaches were operated simultaneously, so that few vehicles would pass two setups.

The size of the setup was such that it was not readily perceived by the driver until he was almost upon it, if he noticed it at all. At that time it did not matter since his speed had already been recorded. The dark green of the meter and the dull brown color of the stool combined to render the setup inconspicuous, particularly at night. Plate VII shows the driver's view of the meter setup.

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*For explanation of statistical terms, see Appendix A.

To prepare a station for operation, the stool was positioned and levelled, and the radar meter placed atop it and aimed. The field crew consisted of two data recorders and the control car driver. At night each recorder was equipped with a flashlight, precautions being taken to shield this light from the view of drivers.

Throughout the time that data were collected, the control car was in almost continuous operation. On approaching an operating station, the driver held a constant indicated speed and alerted the recorder by means of a horn signal. Both driver and recorder kept records of these test runs for later comparison.

Office

Using the known true speed values (V_t) for each indicated speedometer reading (V_s) and the corresponding recorded meter readings (V_r), corrections for each test run were calculated by means of a simple formula:

$$\text{correction} = V_t - V_r$$

These corrections were then plotted, for each setup by direction, against recorded speeds to obtain a correction graph. Corrections from this graph were then applied to all other recorded speeds by rearranging the above formula:

$$V \text{ (estimated true speed)} = V_r + \text{correction}$$

Corrections for truck speeds were made in a somewhat less direct manner. The range of the beam for these vehicles was in the order of 300 to 400 feet because of the much larger target they presented. Therefore, on tangent sections the angular error was negligible. The total of the other corrections, if any, was determined,

based upon the characteristics of the individual setup and radar meter, and this correction applied to the before truck data. On curves, the angular error was slightly less for trucks than for passenger cars and the corrections for the before study were taken as a certain proportion of the passenger car corrections, depending again upon the individual meter and setup. For the after study the tuning fork readings were used to determine truck speed corrections.

Corrected speeds were then grouped and coded to facilitate the calculation of mean speeds and standard deviations. A cumulative frequency graph was drawn, from which were obtained percentile values and a ten mile per hour pace. Examples of the data processing are found in Appendix A.

STATISTICAL ANALYSIS AND RESULTS

Analysis of Zones

The field data were processed to yield values of speed parameters for each station by condition and direction. These parameters were a measure of two characteristics of the speed distribution: the magnitude and the dispersion. The parameters of magnitude are the mean (or average) speed, the 85th percentile speed and the ten mile per hour pace; those of dispersion, or "spread," are the variance (or standard deviation) and the percent in the pace.

The first phase of the analysis consisted of an investigation of the observed changes in each parameter at each station from day to night before and from night before to night after. These three phases will be referred to hereafter as the day, night and after studies, respectively. Mean speeds and variances were analyzed statistically, by which means it was possible to infer whether the observed differences were or were not due to an actual change in the parameter. Frequency polygons of a qualitative nature were constructed for different types of stations. These frequency polygons for passenger cars are shown in Figure 8, the classes labelled -, 0, + indicating the direction of change as a decrease, lack of change, or increase, respectively. The shaded portions denote those stations where the statistical test indicated evidence of an actual change in the parameter at the five percent level of significance*. The unshaded portions in the - and + classes denote a possible change, where the absolute value of the t statistic

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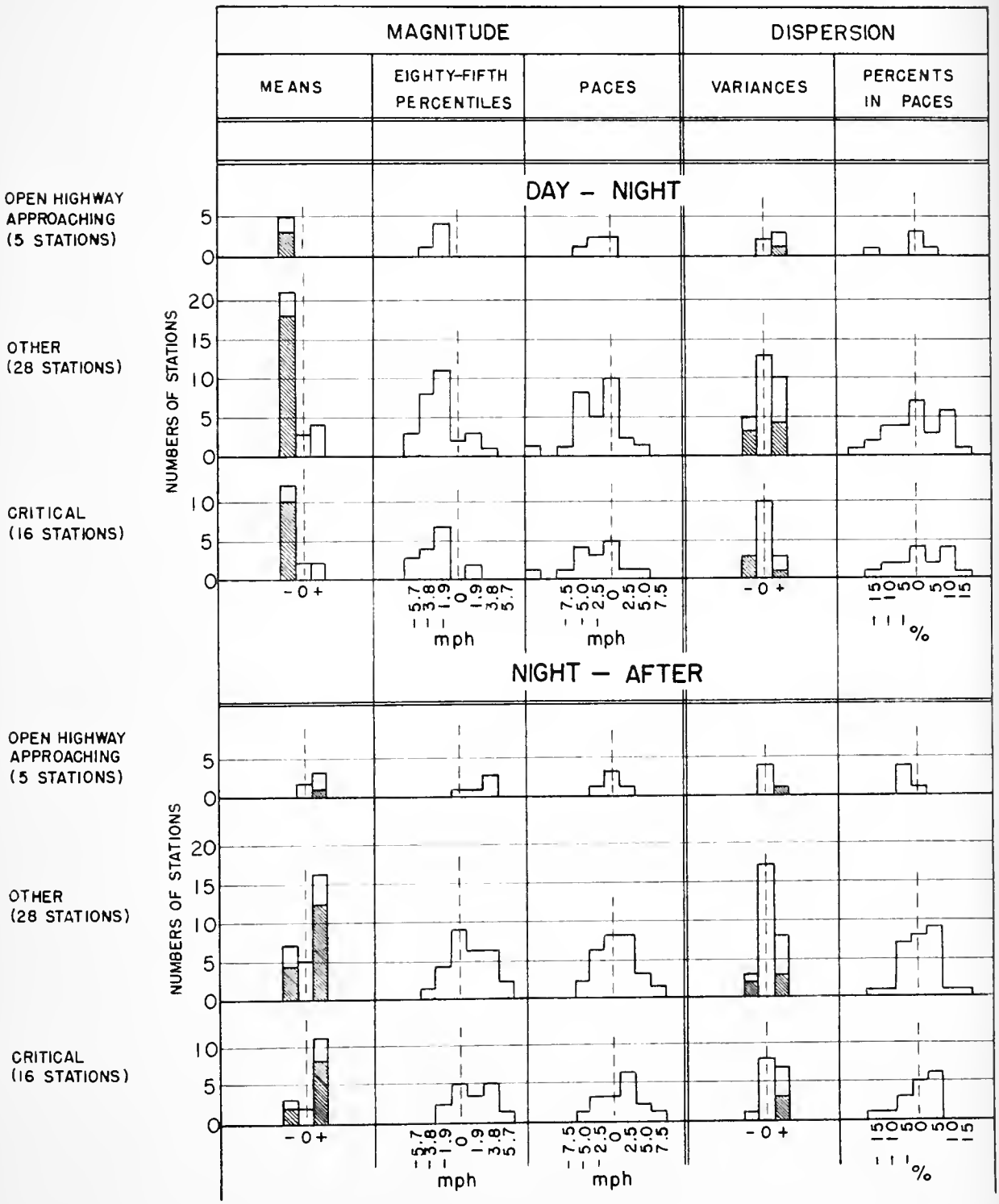
*The probability of a change as large or larger than that observed being due to chance alone is five percent or one in twenty.

FREQUENCY POLYGONS

CHANGES IN PARAMETERS

PASSENGER CARS



LEGEND:

Means

$|t_o| > 1.0$

$|t_o| > t_c$*

-or +

Variances

$|F_o| > 1.2$

$|F_o| > F_c$*

-or +

* i.e. significant at 5% level

FIGURE 8

used in the test on the difference of means was 1.00 or more and the absolute value of the F statistic used in testing the variance was 1.2 or more. This was incorporated into the analysis as a further aid in spotting any trends. The criteria chosen would correspond to a lower level of significance (roughly 30 percent).

No statistical tests are available to analyze changes in the pace or percent in the pace. Changes in the 85th percentile could have been analyzed statistically but, since the variance of the distribution of differences between 85th percentiles was over six times the variance of the differences between means, the available sample sizes were too small to have yielded any reliable results. Consequently, changes in these parameters could not be subjected to a rigorous analysis but were merely grouped into frequency polygons from which it was hoped that general observations of any trend in the changes could be made. Referring to Figure 8, a change in the pace from, for example, 36-46 miles per hour to 34-44 miles per hour was a change of minus two miles per hour; a change in the percent in the pace from 55 percent to 65 percent was a plus ten percent change (ten percent more of the traffic was traveling at speeds within the limits of the pace).

Those rows labelled "open highway - approaching" consist of the changes in parameters at stations which were situated at a sufficient distance from the sites so that no changes should have occurred between the night and after phases due to the addition of delineation. "Other" refers to those stations which, it was felt, were more likely to have been affected, i.e., those in the approach, critical and recovery zones. "Critical" stations were also analyzed separately and

were those at or in the critical zones, i.e., at the entrance to, exit from, or center of a critical feature (curve, bridge, etc.).

Inspection of these frequency polygons (including breakdowns for other types and combinations of zones that are not shown) indicated that parameters of magnitude decreased from day to night while those of dispersion showed a very slight tendency to increase, this tendency having no statistical significance.

The decrease in mean speeds was roughly in the order of one to five miles per hour from day to night. Those stations at which speeds did not decrease were at places where reduced visibility did not allow recognition of the need for, or the advisability of, reduced speed; or where lower night volumes might tend to obviate, in the mind of the motorist, the advisability of reduced speed.

The effect of darkness on truck speeds was not consistent, increases as well as decreases having been observed. For the most part, the speed profiles (see Figure 11) were more uniform at night than during daylight hours.

Parameters of magnitude apparently increased after the placement of added delineation while no changes were apparent in the dispersions. The additional delineation appears to have produced a more uniform speed profile by inducing a decrease in deceleration and acceleration rates; however, the delay in decelerating may have resulted in a more rapid reduction in speed at a critical feature.

Truck speeds were apparently unaffected by the additional delineation.

This evidence would lead one to conclude that added delineation tended to increase night speeds were it not for the fact that

a similar pattern of change apparently occurred at the open highway - approach stations. Whereas the proportion of increases appeared to be slightly greater at the critical zones than at the open highway approach zones, the difference was not great enough nor the number of stations involved sufficient to enable any surmises to be drawn.

Consequently, further tests were deemed advisable with the objective of comparing the degree of change in the means between types of zones. The observed t values used in testing the difference between means were regarded as random variables and the average t for each of the types or combination of zones calculated. The first series of tests along these lines was designed to analyze the trend in changes at each type of zone, i.e., to determine, to a specified probability, whether $\bar{t}_o$ differed from zero for the individual zone.

It was found that, at the five percent level of significance, there was sufficient evidence to conclude that night speeds tended to be generally lower than day speeds for all zones except the recovery and open highway - leaving zones. (The test on the latter was significant at the ten percent level.)

The same test on the night-after $\bar{t}_o$ yielded sufficient evidence to conclude that speeds tended to be generally higher during the after phase of the study for all zones except the approach and recovery zones. Changes in deceleration and acceleration rates in the vicinity of the critical zones were suggested by this fact.

Since there was evidence of an increase in speeds at the open highway approach zones it was desired to determine whether there were

any differences in degree between the changes at each type of zone. It was thought that a more definite picture of what had happened, could, therefore, be obtained if tests were performed on the differences between the $\bar{t}_o$'s for different zones.

The results of this last series of tests were far from illuminating, however. There was no reliable evidence derived from them of any difference between the changes at one zone from those at any other.

On the basis of these findings the possibility is strongly suggested that there may have been a change in the characteristics of the traffic being sampled between the times that the before and after field studies were conducted. If this possibility, however, is discounted it appears that the additional delineation tended to increase night speeds but in a non-consistent manner, indicating that other factors may have been operating more strongly on the motorists' choice of speed. In any event, the differences in speed patterns, while statistically meaningful, were not large and of very little practical significance.

Some of the elements which may have given rise to a change in conditions and factors which led to the inconsistency of results are discussed in a following chapter.

Analysis of Individual Locations

Figures 9 - 12 show the speed profiles, by direction, at each location. Acceleration and deceleration patterns were inferred from these profiles, although it must be remembered that these are plots of discrete spot speeds. Since no two adjacent stations were observed simultaneously these patterns are inferred from data collected on

different days and no exact conclusions can be drawn from them. What is intended is merely a description of what seemed to have taken place. This discussion will be confined primarily to a comparison between the night-before and night-after mean speeds.

Location I (Fig. 9)

Northbound: Open highway approach speeds were about the same, but the variance of the after speeds was higher (the speed distribution was more spread out). No differences existed at the approach to the bridge. Deceleration apparently decreased after the approach zone so that speeds entering the bridge were higher; however, acceleration did not occur on the bridge as it had before so that speeds leaving the bridge were about the same although the variance was greater. Speeds on the curve were higher but acceleration again did not occur on leaving the curve so that vehicles approached the speed zone at lower speeds.

Southbound: No changes were observed from the speed zone through the curve to the entrance of the bridge; deceleration did not occur as before so that speeds leaving the bridge were higher. Acceleration beyond the bridge diminished so that speeds in the recovery and open highway zones were unchanged. The variance at each station was unchanged so that, on the average, most vehicles seemed to have been affected the same way.

The additional delineation seemed to have produced a more uniform speed pattern, but not necessarily a safer one since speeds increased at a hazardous location. This apparent decrease in acceleration and deceleration could be due either to a distracting aspect

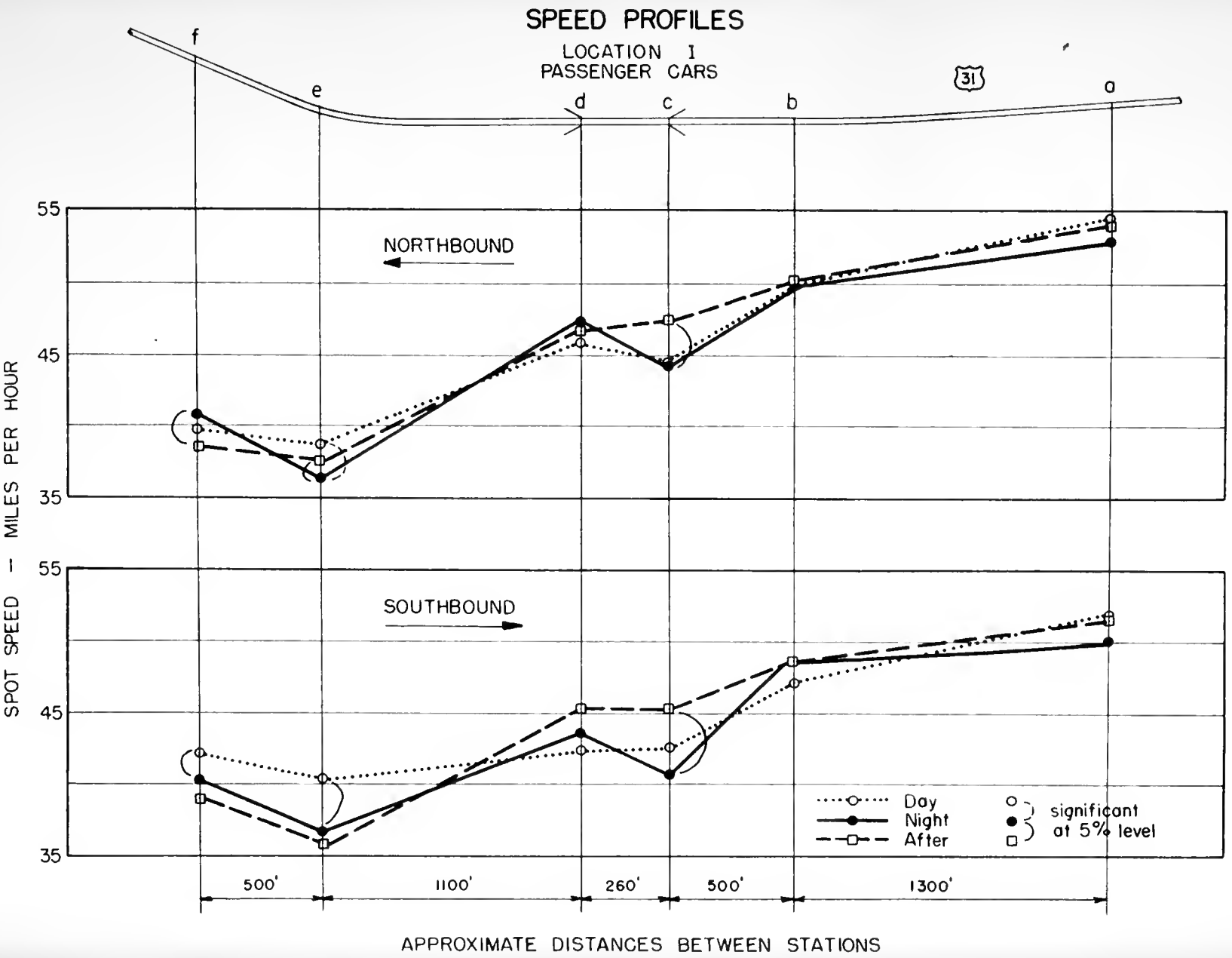

SPEED PROFILES
LOCATION I
PASSENGER CARS
f
e
d
c
b
a
31
NORTHBOUND
SOUTHBOUND
55
45
35
SPOT SPEED - MILES PER HOUR
Day
Night
After
significant
at 5% level
500'
1100'
260'
500'
1300'
APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE 9

of the delineation or to a feeling of confidence mixed with caution. Perhaps the optimum solution, short of relocating the route, would be to extend the 40 miles per hour speed zone beyond the bridge, particularly since residential and commercial development is occurring in that area.

Location II (Figs. 10 and 11)

Northbound (passenger cars): Speeds on U. S. 52 were relatively unchanged prior to the south curve. Speeds on this curve were lower and the variance greater after delineation. Speeds entering and through the intersection curve were unchanged but both mean speed and variance increased at the recovery zone beyond the intersection. The open highway - leaving speeds were higher. On U. S. 41 the open highway - approach speed was unchanged, but the mean speed and variance were greater at the base of the hill at station i. It is at this point that vehicles encounter edge lines.

Southbound (passenger cars): Open highway speeds on U. S. 52 were the same; speeds at the approach to the intersection curve were somewhat higher (the magnitude of the change was small but a large sample size led to statistical significance) and the variance had decreased. Deceleration was unchanged, as were speeds, on the intersection curve. Acceleration out of the curve diminished so that speeds leaving the intersection were lower. Deceleration and acceleration in the vicinity of the south curve apparently diminished since speeds were higher on the curve but unchanged at the recovery zone. Acceleration beyond the curve was apparently delayed because speeds at the open highway zone were higher. Both the mean speed and the variance

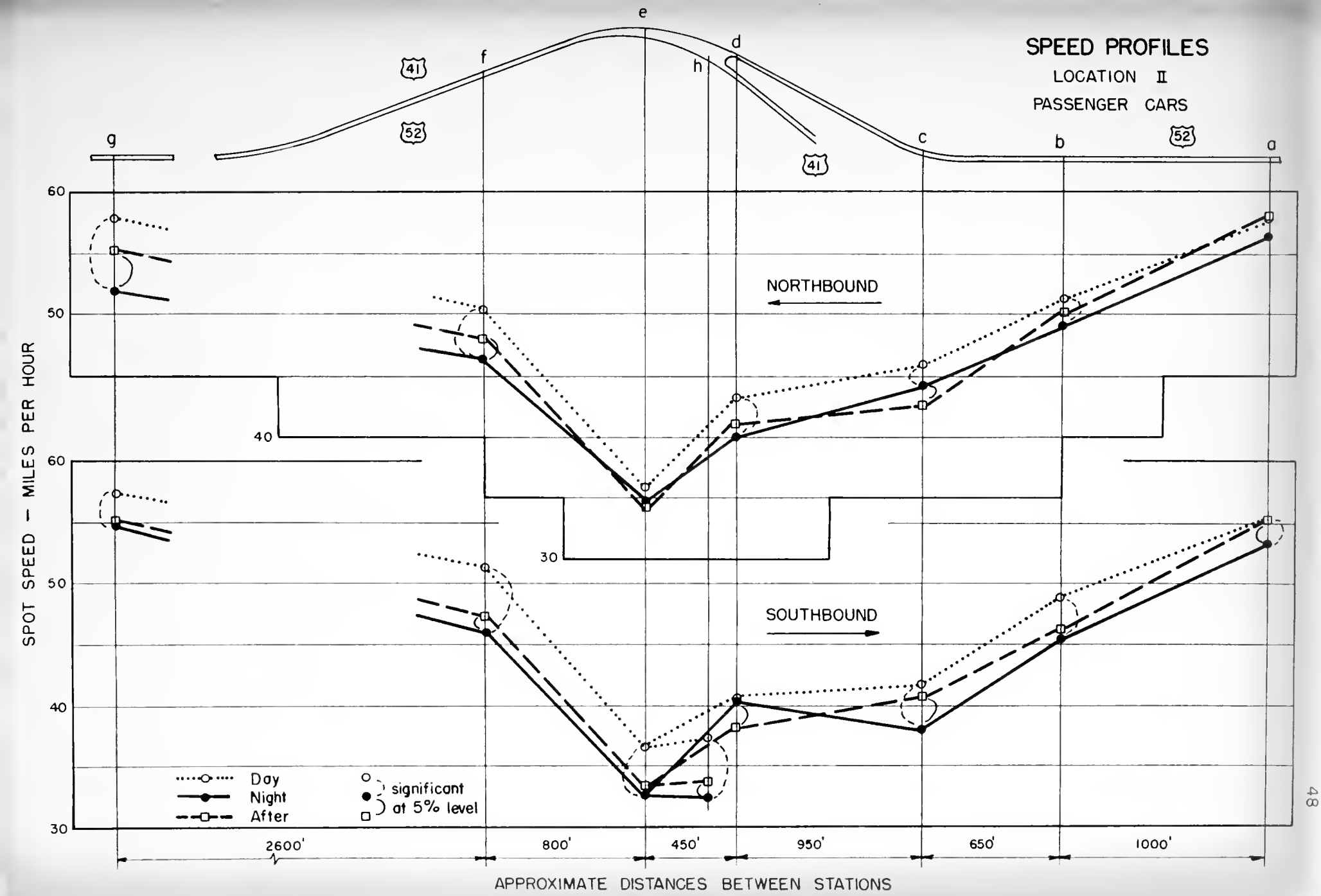

SPEED PROFILES
LOCATION II
PASSENGER CARS
e
d
f
h
41
52
g
c
b
a
NORTHBOUND
SOUTHBOUND
40
30
60
50
40
30
SPOT SPEED - MILES PER HOUR
Day
Night
After
significant
at 5% level
2600'
800'
450'
950'
650'
1000'
APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE 10

increased at station h, where vehicles leave the intersection going to U. S. 41. Speeds on U. S. 41 were higher beyond the railroad overpass (not shown on Figure 10).

Northbound (trucks): No changes occurred except for lower speeds at the recovery zone after the intersection. The variance at the south and intersection curves increased while that at the open highway - leaving zone decreased.

Southbound (trucks): Speeds were unchanged through the intersection except for a decreased variance at the approach to the intersection. Speed was higher at the south curve. Speeds were unchanged at the recovery zone but lower at the open highway - leaving zone. The observed mean speeds of the after study were almost identical in magnitude at the four stations from the intersection curve to the recovery zone beyond the south curve. Higher speeds and a lower variance were observed at station h. Lower speeds were in evidence thereafter on U. S. 41 (not shown in Figure 11).

More changes in traffic control devices and delineation were made at this location than at any other. Moreover, this was the only one of the locations at which major signing changes were made and at which channelizing islands were introduced. Consequently, it is not surprising that the most marked effects did occur here and that these effects were not consistent. Rates of acceleration and deceleration apparently increased in the northbound direction but decreased southbound. In many places acceleration and deceleration were apparently delayed.

Both car and truck speeds were increased at station h. Because the channelizing islands delineate the path to U. S. 41 the

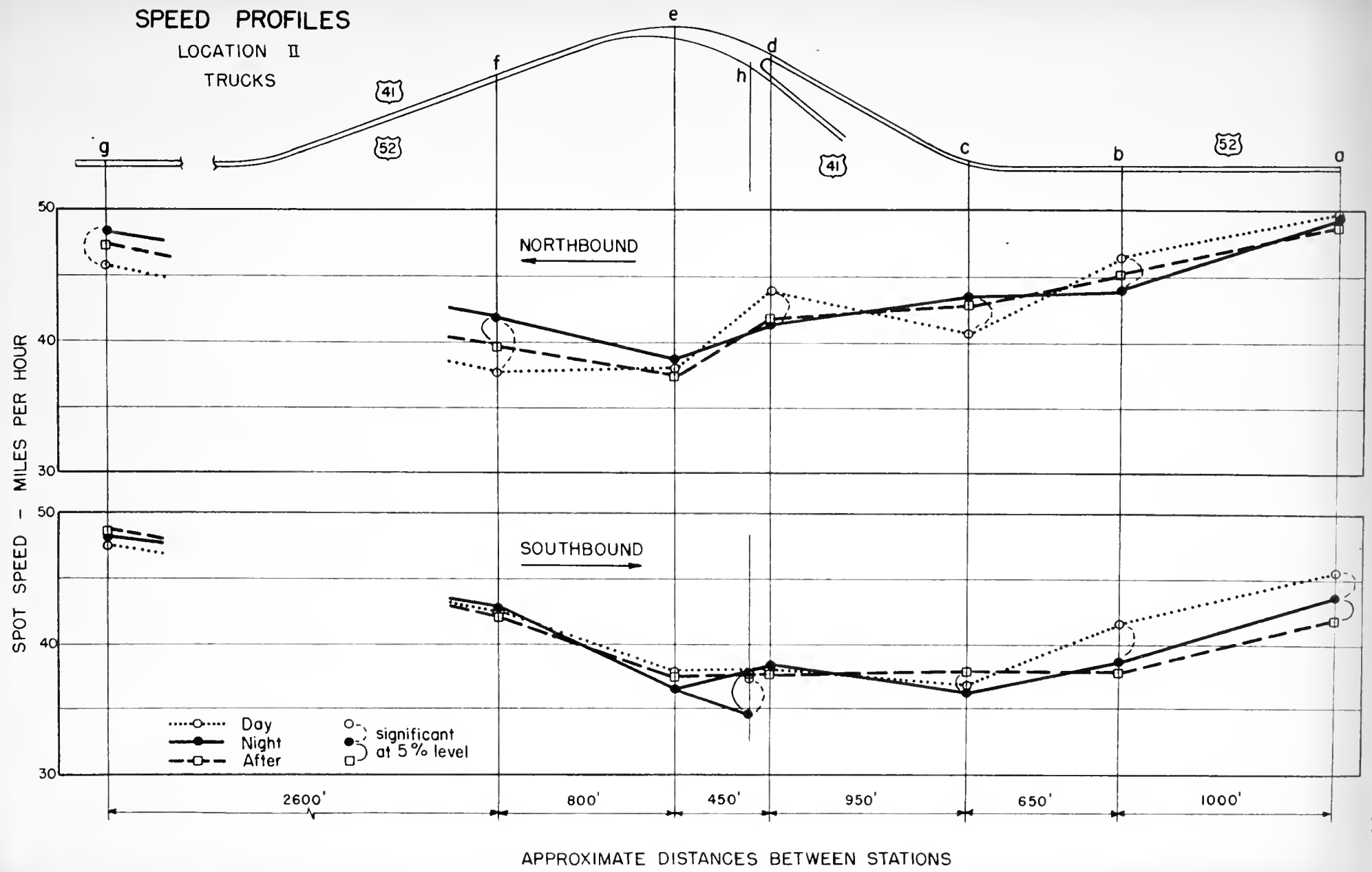

SPEED PROFILES
LOCATION II
TRUCKS
g
f
e
d
h
c
b
a
41
52
52
41
NORTHBOUND
SOUTHBOUND
50
40
30
50
40
30
SPOT SPEED - MILES PER HOUR
Day
Night
After
significant
at 5% level
2600'
800'
450'
950'
650'
1000'
APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE II

accelerating action can be more confidently and quickly initiated. Some of the delay has probably been shifted to the new decision-making area directly prior to the island. There seemed to be less confusion at the junction on the part of southbound motorists but the present situation may be more hazardous as there is less room to maneuver around vehicles stopped at the nose of the island.

Some cars and trucks made turns in the wrong directions through the channels or cut over the sandbags to get back onto U. S. 52. The latter maneuver has probably proved more difficult now that permanent islands and dividers are in place.

The results of statistical tests on the variance of the combined truck and passenger car spot speed distributions showed no significant trend. The majority of tests indicated no changes whatsoever.

Location III (Fig. 12)

Southbound: Open highway speeds approaching the location from the north were higher. Speeds at the approach zone, where vehicles entered the delineated section, were apparently (but not statistically) lower, signifying that deceleration may have occurred sooner due to the added delineation. However, deceleration on the approach to the intersection proper apparently decreased since speeds were higher through and beyond the intersection. Whether this was due to the delineation or to generally higher speeds during the after phase cannot be determined.

Northbound: No difference was observed in the open highway - approach speed. However, the variance had decreased.

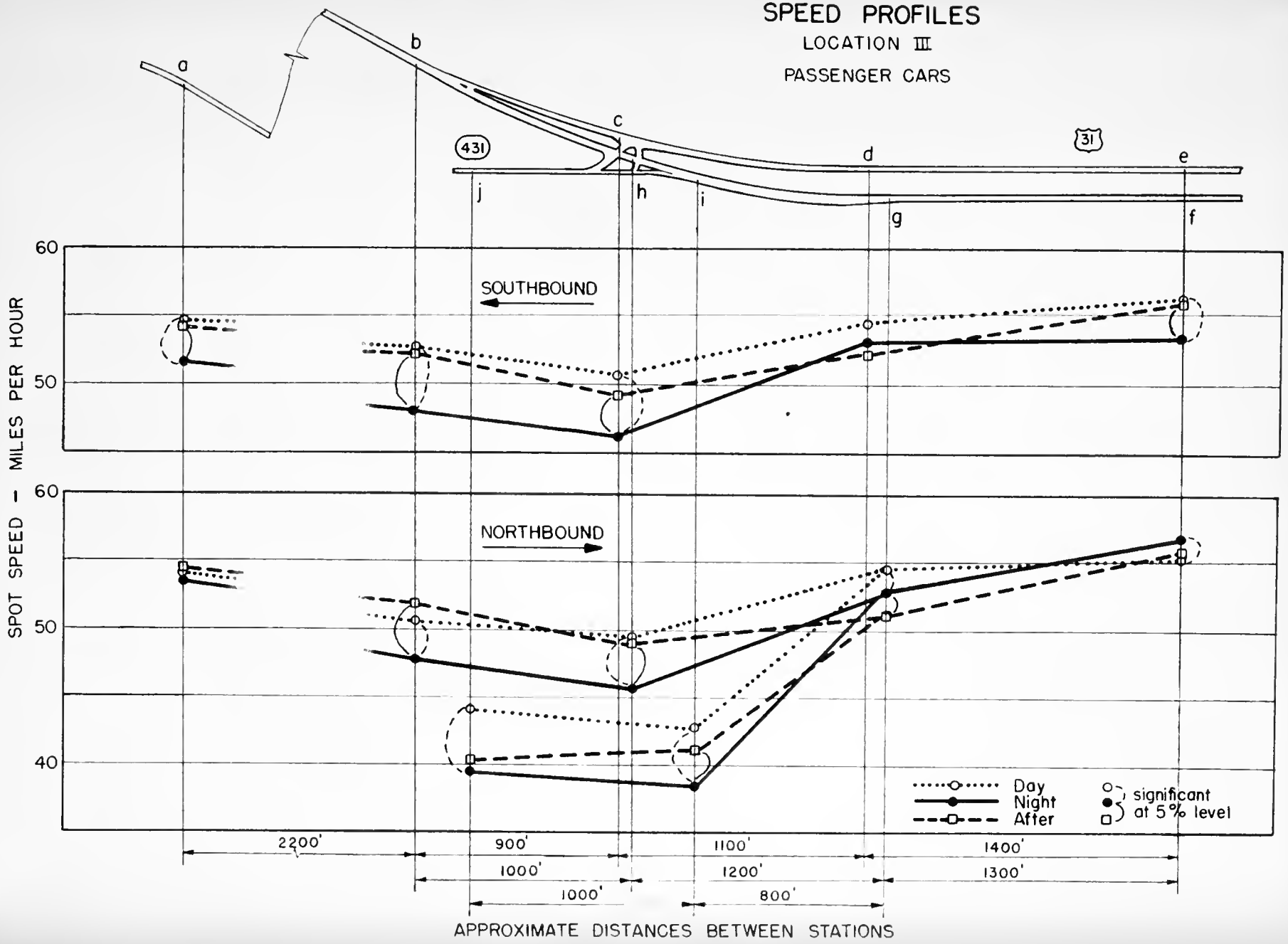

SPEED PROFILES
LOCATION III
PASSENGER CARS
a
b
c
d
e
f
g
h
i
j
431
31
SOUTHBOUND
NORTHBOUND
SPOT SPEED - MILES PER HOUR
60
50
40
Day
Night
After
significant
at 5% level
2200'
900'
1000'
1000'
1100'
1200'
800'
1400'
1300'
APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE 12

Speeds on the approach to the transition section were higher as were those in the intersection. Speeds on the approach to the intersection on S. R. 431 were unchanged but acceleration to the merging area was greater. The merging of both these streams occurred under less acceleration apparently, because the mean speed at the recovery zone, where delineation ended, was lower. Acceleration was apparently the same thereafter but at lower speeds (unless it was delayed and took place beyond the area in which data were collected).

EVALUATION OF STUDY CONDITIONS

A common method of conducting experimental research is to provide causes and note effects. In order to be able to confidently ascribe specific effects to specific causes it is usually necessary to hold all other factors constant. In a study of traffic behavior, however, it is not always possible to achieve a state of constancy; indeed, we are often not aware of all the factors which may be operating nor which of those we are aware of are significant.

In retrospect, it would appear that there were circumstances, some of which were unavoidable and others of which were unforseeable, which may have interfered with the control of this experiment. Among these are the intrinsic dissimilarities between any possible locations which would make for lack of control in terms of correlation between them, particularly since hazardous locations are often atypical ones. Aggravating this situation was the lack of uniformity of conditions, e.g., the presence of speed zones, requirements for different types and extents of added delineation, different physical features, etc.

In performing a before and after study to determine the effect of a given device it must be assumed that the traffic involved is "constant," i.e., that it would exhibit the same characteristics both before and after were it not for the presence of the device in question. When dealing with the human element, one encounters a factor which is at the same time both random and subject to motivation. What these motivations are, in terms of incitement to a specific course of action is something about which one can often only guess. For this reason, the significance of many of the conditions which

developed could not be evaluated with respect to their effect on this study.

During one phase or another of the field study, road construction or repairs were taking place several miles from each of the locations. To what extent this and the possible detouring of traffic affected the composition of traffic at the sites is not known. It also happened that the summer months during which the before phases were conducted exhibited an abnormally high incidence of rainfall. That and the length of time it took to gather data caused the after study to extend into the fall when darkness and, therefore, the commencement of data collection occurred at an earlier hour (particularly after the changeover from daylight saving time). This may also have led to differences in the composition and volumes of traffic between phases.

One major obstacle was the low volumes encountered and the consequent inability to acquire samples large enough in size to cope with the large variances and small changes observed. To do so would have at least doubled the time necessary to conduct the field study and might have further intensified the effects of the factors mentioned above. To limit the study to fewer locations would have meant that any effects observed would have been true only of those locations studied.

Finally, judging from the experience of this study, it would appear that there is need for improvement in the field of speed measuring devices. Characteristics which are desirable in such a device are: reliability - freedom from the possibility of the occurrence of non-random errors; precision - small random error so that better accuracy can be attained from a given sample; portability - it should

not entail elaborate equipment which would require an excessive amount of time and care in setting up; ease of operation - the observer should be able to take data with a minimum of operations; direct reading - these data should be as close to final form as possible and require little, if any, additional calculations; versatility - ability to be conveniently operated over one or two lanes, as desired, with no loss in reliability; appearance - as inconspicuous as possible.

SUMMARY AND RECOMMENDATIONS

From the data herein described it may be concluded that:

1. With few exceptions, passenger car night speeds were lower than daytime speeds with most changes in the range of one to five miles per hour. The exceptions were at stations where reduced visibility did not allow recognition of the need for, or the advisability of, reduced speed; or at stations where lower volumes would obviate, in the mind of the motorist, the advisability of reduced speed.

   Changes in truck speeds were not consistent from day to night, with some increases as well as decreases. Speed profiles for trucks appeared to be more uniform.

2. Few changes in dispersion of the speed distributions between day and night were noted and there was no consistency to those changes that were observed.

3. After delineation, night passenger car speeds showed a tendency to be slightly higher and speed profiles were a little more uniform; however, it could not be determined whether this phenomenon was due to delineation alone, to a change in basic traffic characteristics, or to a combination of circumstances. In any event, the changes noted were small and probably of little practical significance.

Night truck speeds after delineation were virtually unaffected.

4. Dispersion of the speed distributions was apparently not affected by the addition of delineation.

The anomalies present in the results would suggest that factors other than delineation may determine the motorist's choice of speed. It may well be that the effects of delineation do not primarily manifest themselves in changes in speed patterns. Since the fundamental motive behind delineation is safety, and the effect on safety is manifested by accident occurrence, a comparison of the before and after accident records for the locations in question would be of great value and may very well be the only way in which the effect of delineation may be observed.

The before accident records for a 20-month period are included herein. It is recommended that accident records be compiled, at some future date, for a similar period and compared with the extant ones, taking into account traffic volumes, weather experience (many accidents involved wet pavement) and types of accidents.

Considerable interest has been expressed in a speed-illumination study. Such a study could be undertaken with the speed-delineation study as a base. However, it would be advisable to limit the scope of such a study so as to enable the collection of larger samples at more stations. Location III would probably be the best site for such a study. All of the existing stations were chosen with the possibility of an illumination study in mind, but it is

suggested that additional stations be operated in order to fill in the gaps in the acceleration - deceleration profiles.

Such a speed-illumination study should prove to be very profitable as it would compare speed patterns and accident rates under conditions of optimum delineation (presumably, optimum delineation is now in place at the location) with those under conditions of optimum lighting and delineation (since some measure of delineation will be necessary even with illumination). In the study, therefore, that delineation which is now located at the sites and which would be unnecessary due to the presence of luminaires should be eliminated. The results of a speed-illumination study when compared with the results of this study and the recommended accident study should provide important information on the relative value of optimum delineation and the combination of lighting and delineation at hazardous locations.

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APPENDIX A

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NOTATION USED

Population parameter		Corresponding sample statistic
Mean	μ	$\bar{X}$
Variance	σ^2	s^2
Standard deviation	σ	s
Number of elements	N	n
Difference of means	δ	d

α: Level of Significance, (Risk); probability of rejecting a true hypothesis.

$\beta(\theta)$: Probability of not rejecting a false hypothesis if θ is the true value of the parameter.

t: Standard "student's" t statistic, used to test hypotheses on the mean.

t_o: Observed t (calculated from sample) to be tested.

tc: Theoretical t (from "student's" t distribution) for given α, and given number of observations in sample.

F: Function of the F distribution, used to test hypotheses on variances.

F_o: Observed F (calculated from sample) to be tested.

Fc: Theoretical F (from F distribution) for given α and given numbers of observations in the samples.

Σ: Summation sign.

i: Index of summation.

$\sum_{i=1}^{n} x_i$: Sum of all the x_i, where x_i has the values x_1, x_2, x_3, $\cdots x_n$

Σx_i: Short notation for $\sum_{i=1}^{n} x_i$

GLOSSARY OF STATISTICAL TERMS

Population: The total group of elements under investigation.

Sample: A number of elements selected from the population.

Random sampling: A method of sampling where each element of the population has an equal chance of being selected for the sample.

Random variable: A measurable characteristic associated with each random choice of an element from a population, to each of the possible ranges of values of which, there is attached a probability, p, that it lies in that range.

Normal distribution: A certain theoretical relation between values of the measured variable and the relative frequency of the value. The graph of this distribution is commonly known as a "bell" curve.

Population parameter: A numerical characteristic of the population, e.g., the population mean.

Sample statistic: A numerical characteristic of the sample, e.g., the sample (observed) mean.

Arithmetic mean: The arithmetic average value of the elements under investigation. (Commonly referred to as the mean.)

Sample mean: Best estimate of the population mean. The mean of the sample,

$$\bar{X} = \frac{\sum x_i}{n} \qquad (1)$$

$$= \frac{\text{sum of the observed values}}{\text{number of observed values}}$$

Variance: A measure of the variability or dispersion of the values, x, of the random variable. Defined as the average of the squared deviations from the mean.

$$\sigma^2 = \frac{\sum (x_i - \mu)^2}{N} \qquad (2)$$

Standard deviation: Square root of the variance; also known as the "root mean square deviation." Analagous to the radius of gyration in mechanics.

Sample standard deviation: Estimate of the population standard deviation. Calculated by taking deviations from the sample mean.

$$s = \sqrt{\frac{\sum (x_i - \bar{X})^2}{n-1}} \qquad (3)$$

Statistical hypothesis: A statement delimiting the possible values that a population parameter may have.

Note: For further explanation of these terms and the normal distribution, see general references: (1) pp. 16-26, 27, 83-87; (3) pp. 44-45, 59, 65-69; (4) pp. 45-51, 88-89, Chapt. IV; (6) Chapters 2, 3, 5, p. 22.

SOME CHARACTERISTICS OF THE NORMAL DISTRIBUTION

Since the data here assembled are based upon finite samples the element of chance has been introduced. Because of this fact we must attempt to weed out those differences which arise from chance from those which represent a true change. To do this, we make use of the properties of the normal distribution, which is based on the laws of probability.

A normal distribution curve for values of a random variable, x, may be completely described by two physical constants: the population mean, μ, and the population standard deviation, σ. Two thirds of the area under the curve lies between the values, $\mu - \sigma$ and $\mu + \sigma$. Ninety-five percent of the area lies between the values $\mu - 2\sigma$ and $\mu + 2\sigma$. The probability of a value of x lying between any two values A and B is equal to the area under the curve between those values. (See Figure 13).

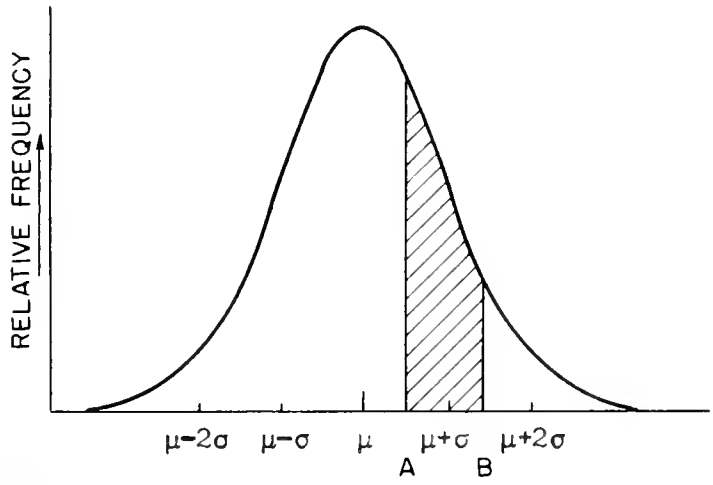

Fig. 13. Distribution of values of random variable, x, drawn from normal population with mean, μ, standard deviation, σ.

Values of means calculated from an infinite number of samples, of size n, taken from a population with mean, μ, and standard deviation, σ, will approximate a normal distribution (Fig. 14). Chance differences in the samples will result in differences in the sample means. The mean of the distribution will be μ, the true mean; the standard deviation will be equal to $\frac{\sigma}{\sqrt{n}}$, also known as the standard error of the mean.

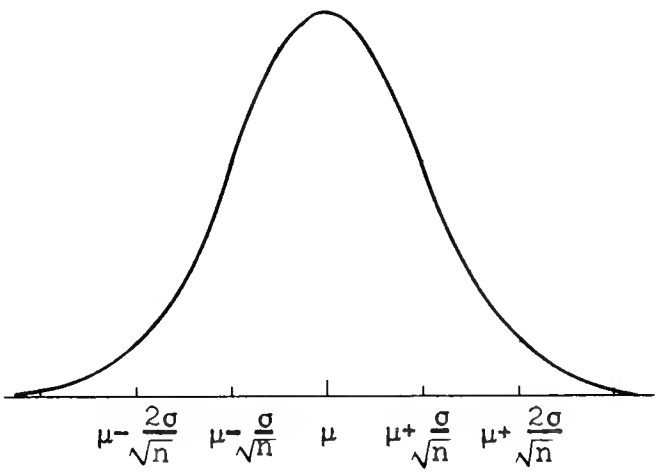

Fig. 14. Distribution of sample means drawn from population with mean, μ, standard deviation, σ.

Differences between pairs of sample means taken from the original population will also approximate a normal distribution (Fig. 15) with mean zero, and standard deviation

$$\sigma_d = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}} \qquad (4)$$

where $d = \bar{X}_2 - \bar{X}_1$.

The quantity σ_d is the standard error of the difference in sample means.

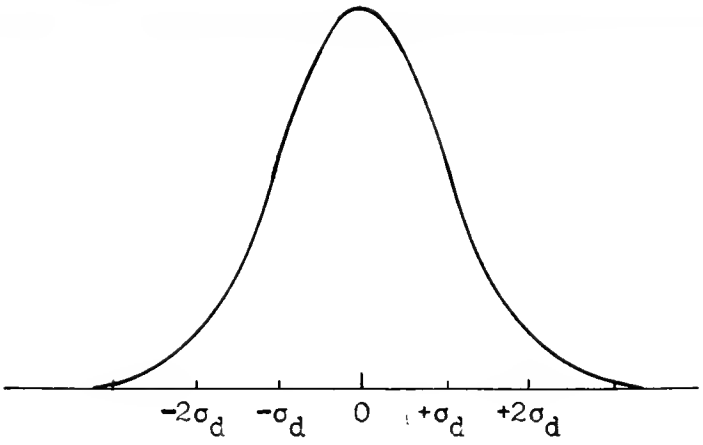

Fig. 15. Distribution of differences between pairs of sample means drawn from the same population. Since the means are drawn from the same population, the expected value of the difference in means, δ, is $\mu - \mu = 0$.

COMPARING BEFORE AND AFTER STUDIES

Testing Hypotheses on the Mean

Let us suppose that two random samples of size n_1, n_2, are taken of spot speeds at the same location on a highway but under different conditions. We wish to determine whether the difference between the observed means $\bar{X}_1$, $\bar{X}_2$, is due to an actual change in means or due to chance variation in the samples. From the properties of the normal distribution we can determine the probability of an observed difference as large as, or larger than, we did observe, being due to chance variation.

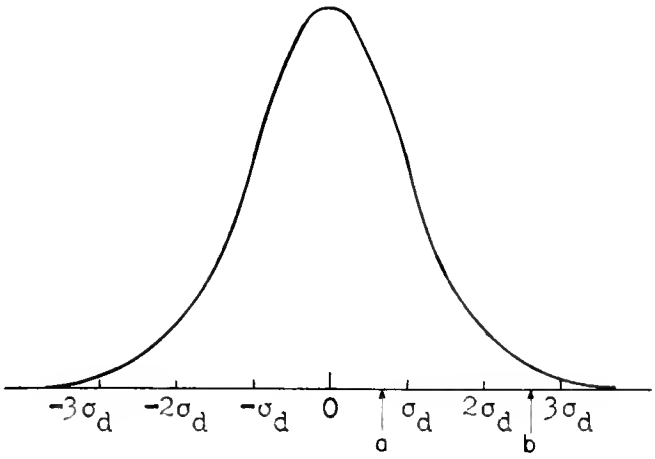

Fig. 16. Same as Figure 15, showing two possible observed differences of means.

Suppose that the value of the observed difference of means falls at a (Fig. 16). The probability is large that this observed difference is due to chance. However, should the observed difference of means fall at b, the probability of this being due to chance is small and we may conclude that this observation may have been derived

from a population with a mean difference not equal to zero. Some arbitrary division point must be chosen (in advance) in regard to how small a probability of the difference being due to chance is acceptable. This procedure is called "testing an hypothesis," the hypothesis being: $\delta = \mu_2 - \mu_1 = 0$.

In performing this test we run the risk of making two types of error. We might err in deciding that the two means come from populations with different mean speeds when they actually come from the same population. The probability of making this type of error is designated by α, which must be chosen in advance. It is the risk, or level of significance. Hence, $\frac{1 - \alpha}{\alpha}$ represents the odds against deciding there is a difference when none exists.

We might also err in deciding that the two means do not represent any real difference when they actually do. The probability of making this type of error will depend on the true difference of the populations (should they actually differ). It can easily be seen that the smaller the true difference the greater the likelihood of making this error, the probability of which is designated as β.

Since we have no way of knowing in advance whether any existing difference would be positive or negative, we must take both possibilities into account and perform a two-sided test with a risk of $\frac{\alpha}{2}$ at each side.

The Test Statistic

Since the shape of the normal curve is dependent solely on the standard deviation and the positioning along the abscissa upon the mean, it is possible to transform the given values of these parameters

to standard values and come up with one single curve for which tables of values can be, and have been, computed. By using the transformation:

$$\text{standard normal deviate} = \frac{x - \mu}{\sigma}$$

we can reduce any normal distribution to deviations from a mean of zero, the standard deviation of the curve being one. Any observed values can be appropriately transformed and compared with values of the standard curve.

In order to be able to use values from a table of standard normal deviates, however, we need to know the true population standard deviation, σ*. Since all that is available to us is the sample standard deviation, s, we must resort to the so-called "t" distribution** which allows for the fact that we are using a standard deviation derived from a relatively small sample and not the true population standard deviation.

Suppose that we are willing to take a 19 to 1 chance that we won't make the first type of error. We can do this by choosing an α level of five percent.

We compute a test statistic for the comparison:

$$t_o = \frac{\bar{X}_2 - \bar{X}_1}{s_d} \qquad (5)$$

From a table of values of the t distribution, we look up, for a five percent level of significance and degrees of freedom

---

*Throughout the preceding discussion we have assumed that no matter what the values of the population means, the standard deviations are equal. Should the standard deviations differ, some modifications in the test will have to be made. This will be discussed later.

**For the theory and uses of the t distribution and tests of hypotheses, see general references: (1) pp. 105-108, 140-142, 148-149, 176-182; (4) pp. 143-145; (6) pp. 26-28, p. 103.

$n_1 + n_2 - 2$*, "critical" values of t. For the two-sided test the notation for the upper limit is $t_{(1 - \frac{\alpha}{2}),\ n_1 + n_2 - 2}$, and for the lower limit, $t_{\frac{\alpha}{2},\ n_1 + n_2 - 2}$. These t_c will be equal in value but opposite in sign. Ninety-five percent of the observed t's should fall in this range if our hypothesis is correct (if the observed difference arises from chance variation).

To perform the test all we need do is compare t_o with the "critical" t's. If the value of t_o falls between the "critical" t's we can conclude that there is no "significance" to the observed difference and we have, therefore, no reliable evidence for rejecting the hypothesis.

However, there is a possibility that values of t_o computed from a population with a mean value of δ (where δ is different from zero) will also fall between $-t_c$ and $+t_c$, in which case we would be making an error of the second kind (see Figure 17). If the mean of this population is δ_2 we can compute $\beta(\delta_2)$ (read β of δ_2). The quantity $1 - \beta(\delta_2)$ is called the "power" of the test for a value δ_2. The smaller the value of $\beta(\delta_2)$, the more powerful the test.

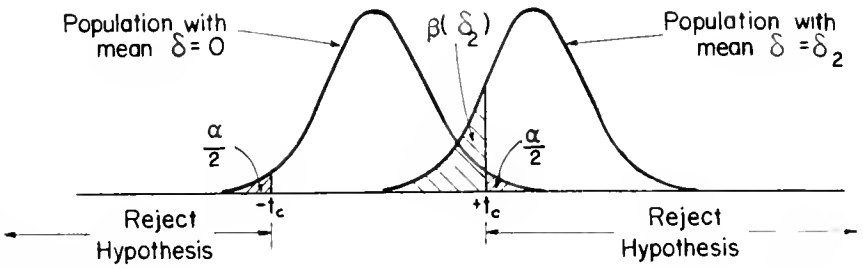

Fig. 17. Two distributions showing how errors in decision making may come about.

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*We get n possible degrees of freedom from a sample of n observations. One degree of freedom is lost whenever deviations are taken from the sample mean instead of the population mean. See general reference (1) p. 27.

Calculation of the t_o Statistic

The test statistic, t_o, is calculated using the estimated standard error of the difference in means, the exact form for which is

$$s_d = \sqrt{\frac{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}{n_1 + n_2 - 2} \left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \tag{6}$$

but if n_1 and n_2 are sufficiently large and of comparable magnitude, this expression can be simplified to the approximate form

$$s_d = \sqrt{\frac{s_1^2}{n_2} + \frac{s_2^2}{n_1}} \tag{7}$$

In either case, we have

$$t_o = \frac{(\bar{X}_2 - \bar{X}_1) - \delta}{s_d} \tag{8}$$

or, since we are testing the hypothesis $\delta = 0$, we have equation (5):

$$t_o = \frac{\bar{X}_2 - \bar{X}_1}{s_d}$$

The foregoing assumes that the standard deviations of the populations being compared are equal. Should this not be the case, modifications in the t test must be made.

Where the test on the standard deviations is significant, the value of the test statistic is given by

$$t_o = \frac{\bar{X}_2 \quad \bar{X}_1}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{9}$$

and the critical value by

$$t_c = \frac{\left(\frac{s_1^2}{n_1}\right) t_{\frac{\alpha}{2},\, n_1 - 1} + \left(\frac{s_2^2}{n_2}\right) t_{\frac{\alpha}{2},\, n_2 - 1}}{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \qquad (10)$$

Where the test on the standard deviations is inconclusive (close to significant), either form may be used.

Testing Standard Deviations (or Variances)

Tests on standard deviations actually involve tests on the variance, which is equivalent to the square of the standard deviation. The comparison of variances is based on the F distribution*.

As in the t test, the F test involves the comparison of an observed test statistic, F_o, with tabulated values of F_c derived from the properties of the F distribution. F_o is calculated by taking the ratio of the observed variances

$$F_o = \frac{s_1^2}{s_2^2} \qquad (11)$$

where, for the purposes of this test, s_1^2 is always the greater of the two variances. Therefore, F_o will always be greater than 1.00.

Again, a level of significance, or risk (α), must be chosen in advance. Critical F values (F_c) are read from a table of the F distribution with degrees of freedom $n_1 - 1$ for s_1^2, and $n_2 - 1$ for s_2^2. The notation for F_c is

$$F_{(1 - \frac{\alpha}{2}),\, (n_1 - 1,\, n_2 - 1)}$$

---

*For the theory and use of the F distribution, see general references: (1) pp. 108-110, 192-195; (4) p. 147; (6) pp. 31, 49, 91-93.

The hypothesis that the variances (and hence, the standard deviations) are equal is not rejected if $F_o < F_c$.

Tests on the variability of the combined distribution of truck and passenger car speeds were made by comparing the combined variances (s_c^2) which were easily calculated using data that was already available.

The combined variance is similar to a weighted average of the individual variances, with allowance being made for the difference in means from which deviations were taken. This quantity is given by

$$s_c^2 = \frac{n_p s_p^2 + n_t s_t^2 + n_p(\bar{X}_p - \bar{X}_c)^2 + n_t(\bar{X}_t - \bar{X}_c)^2}{n_p + n_t - 2} \quad * \qquad (12)$$

where $\bar{X}_c$ is the weighted average of the passenger car mean speed and the truck mean speed.

$$\bar{X}_c = \frac{n_p \bar{X}_p + n_t \bar{X}_t}{n_p + n_t} \qquad (13)$$

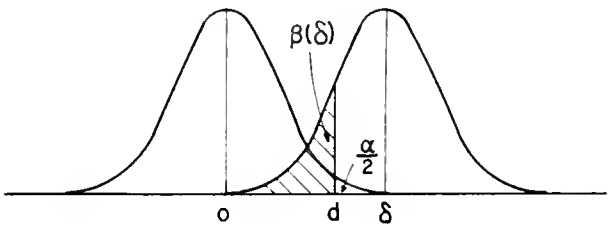
Comparisons of the combined variances were made by means of the F test.

---

*See general reference (3) p. 47.

MINIMUM SAMPLE SIZE FOR SPECIFIED DEGREE OF CERTAINTY

Since all that is really needed is the approximate minimum sample size we may make certain simplifying approximations. We will assume $\sigma_1 = \sigma_2$ and perform the computations on the basis that $s_1 = s_2$. It is anticipated that the sample size, n, will be sufficiently large so that the values of the t distribution will closely approximate the values for the normal distribution.



Let d equal a value of observed difference corresponding to the critical t of the distribution with mean equal to zero.

For the distribution with a mean of zero:

$$t_{(1 - \frac{\alpha}{2})} = \frac{d - 0}{\sqrt{\frac{s^2}{n} + \frac{s^2}{n}}}$$

for the distribution with mean equal to δ:

$$t_{\beta(\delta)} = \frac{d - \delta}{\sqrt{\frac{s^2}{n} + \frac{s^2}{n}}}$$

If α is chosen as .05 and it is desired that, for a hypothetical value of $\delta = 3$, $\beta(3)$ be less than .10, then the t values above become

$$t_{.975} = 1.96$$

$$t_{.10} = -1.28$$

Substituting 3 for δ and taking the difference eliminates d:

$$t_{.975} - t_{.10} = \frac{3}{\sqrt{\frac{2s^2}{n}}} = 3.24$$

For various values of s, the corresponding required n may be calculated.

COMPUTATIONAL FORMULAS AND CODING METHODS FOR SAMPLE MEAN AND STANDARD DEVIATION

The sample mean, $\bar{X}$, is the arithmetic average of all the observations. Where a value, x_i, is observed a number of times we can compute the sample mean as a weighted average based on the frequencies of observation of the values.

Let the subscript i represent any cell, x_i, the value of the cell, and f_i, the number of observations in that cell. For instance, should the lowest observed value be 32 mph, with three observations at 32 mph, and the highest, 55 mph with two observations, $x_1 = 32$, $f_1 = 3$; $x_2 = 33$, etc; $x_{24} = 55$, $f_{24} = 2$.

Therefore, the mean can be calculated by taking the average of the products $f_i x_i$. It can be seen that $\sum f_i = n$, since the sum of the numbers of observations in each cell is equal to the total number of observations.

$$\bar{X} = \frac{\sum f_i x_i}{\sum f_i} = \frac{\sum f_i x_i}{n}$$

In computing the standard deviation it would be tedious, indeed, to have to compute the squares of all the individual deviations, so we can again take advantage of the fact that many values will be repeated. This leads to the formula

$$s = \sqrt{\frac{\sum f_i (x_i - \bar{X})^2}{n - 1}} \qquad (14)$$

However, we would still have to square the deviations of the cell values, x_i, from the mean. A much simpler formula to use in

calculations can be derived by squaring and expanding equation (14).

$$s^2 = \frac{1}{n-1} \sum f_i (x_i^2 - 2x_i\bar{X} + \bar{X}^2)$$

Substituting $\frac{\sum f_i x_i}{n}$ for $\bar{X}$ and removing parentheses we get

$$s^2 = \frac{1}{n-1} \left[\sum f_i x_i^2 - 2 \sum f_i x_i \left(\frac{\sum f_i x_i}{n} \right) + \sum f_i \left(\frac{\sum f_i x_i}{n} \right)^2 \right]$$

Substituting n for $\sum f_i$ in the third term inside the bracket gives

$$s^2 = \frac{1}{n-1} \left[\sum f_i x_i^2 - 2 \frac{\left(\sum f_i x_i \right)^2}{n} + n \frac{\left(\sum f_i x_i \right)^2}{n^2} \right]$$

Collecting like terms simplifies this to

$$s^2 = \frac{1}{n-1} \left[\sum f_i x_i^2 - \frac{\left(\sum f_i x_i \right)^2}{n} \right]$$

which reduces to

$$s = \sqrt{\frac{n \sum f_i x_i^2 - \left(\sum f_i x_i \right)^2}{n(n-1)}} \qquad (15)$$

the terms of which can be easily computed.

These calculations can be simplified further by grouping the data into larger cells and giving each observation in the group the value of the cell midpoint. For example, the values 32, 33, and 34 could be grouped in one cell with the mid value of the cell equal to 33. Any observation with a value between 31.5 and 34.5 would be placed in this cell. Observations falling at the boundary, should the boundary be common to two adjoining cells, can be split between the cells concerned. These cells could then be coded by choosing any one cell as an arbitrary origin and giving the cells designations, or codes, corresponding to the distance, in cell widths, that the individual cell is above or below the origin. The first cell above the

origin would be given a code of +1, the second +2, etc.; the third cell below the origin would have the code -3, etc.

x_g = average value of cell (midpoint)

z_g = coded value of cell
= algebraic order above or below origin

$$z_g = \frac{x_g - x_o}{w} \tag{16}$$

x_o = midpoint of cell designated as origin

f_g = number of observations in cell

w = width of cell (upper boundary minus lower boundary)

Coding the cells enables us to work with smaller integral numbers. We can now treat the z_g as we would the x_g or x_i.

$$\bar{Z} = \frac{\sum f_g z_g}{n} \quad \text{is the average coded value;} \tag{17}$$

multiplying this by w gives the average value in mph relative to the origin, so we add x_o to $w\bar{Z}$ to get the sample mean

$$\bar{X} = w\bar{Z} + x_o \tag{18}$$

Similarly, we calculate

$$s_z = \sqrt{\frac{n\sum f_g z_g^2 - (\sum fz)^2}{n(n-1)}} \tag{19}$$

Multiplying s_z by w to transform the units back to miles per hour gives the sample standard deviation as

$$s = ws_z \tag{20}$$

ILLUSTRATIVE EXAMPLES

Processing of Raw Data

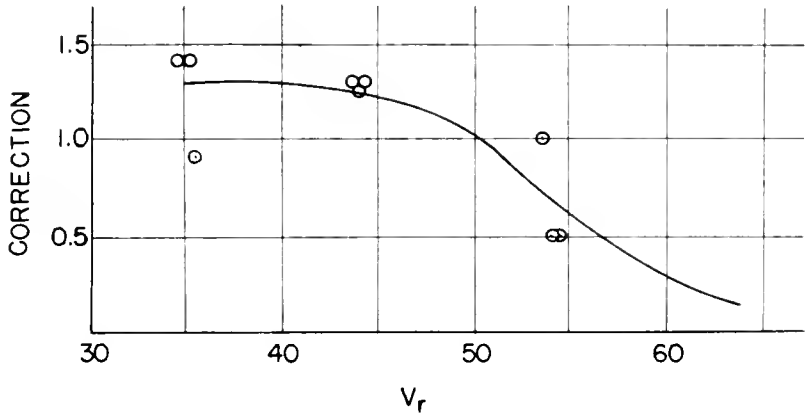
The data in the following examples are from the sample taken at Location II, station b, of southbound passenger cars during the after study.

Example 1: Correction of Field Data.

Corrections were computed from the test car run data.

V_s	V_r	V_t	Correction = $V_t - V_r$
40	35	36.4	+1.4
40	35	36.4	1.4
40	35.5	36.4	0.9
50	44	45.3	1.3
50	44	45.3	1.3
50	44	45.3	1.3
60	54	54.5	0.5
60	53.5	54.5	1.0
60	54	54.5	0.5

These corrections were then plotted against recorded speeds.



After the correction graph was drawn, the field data were corrected and grouped as shown below.

(Ex. 1, continued)

V_r	C	Grouped V	Tally	Cell Frequency
31	+1.0	32		
32	1.0	33	I	1
33	1.0	34		
34	1.0	35	I	
35	1.0	36		4
36	1.0	37	III	
37	1.0	38		
38	1.0	39	⧻	9
39	1.0	40	IIII	
40	1.0	41	III	
41	1.0	42	⧻	13
42	1.0	43	⧻	
43	1.0	44	⧻ II	
44	1.0	45	⧻ IIII	20
45	1.0	46	IIII	
46	1.0	47	⧻ I	
47	1.0	48	IIII	16
48	1.0	49	⧻ I	
49	1.0	50	III	
50	1.0	51	⧻ IIII	14
51	0.5	51.5	II	
52	0.5	52.5	I	
53	0.5	53.5	I	7
54	0.5	54.5	⧻	
55	0.5	55.5	I	
56	0.5	56.5	I	
57	0.5	57.5		2
58	0	58		
59	0	59		
60	0	60	I	2
61	0	61	I	

The grouped data were then coded and processed to get the sample mean and standard deviation, and cumulative frequency points as in Example 2.

Example 2: Calculation of Sample Mean and Standard Deviation, and Cumulative Frequency Points.

Midpoint	Interval	f	z	fz	fz^2	Cumulative f	Percent Cumulative f
33	32-34	1	-4	-4	16	1	1.1
36	35-37	4	-3	-12	36	5	5.7
39	38-40	9	-2	-18	36	14	15.9
42	41-43	13	-1	-13	13	27	30.7
45	44-46	20	0	0	0	47	53.4
48	47-49	16	1	16	16	63	71.6
51	50-52	14	2	28	56	77	87.5
54	53-55	7	3	21	63	84	95.5
57	56-58	2	4	8	32	86	97.7
60	59-61	2	5	10	50	88	100.0
		$n = 88$		$\Sigma fz = +36$	$\Sigma fz^2 = 318$		

(Ex. 2, continued)

$$\bar{X} = w\bar{Z} + x_o = 3\left(\frac{36}{88}\right) + 45 = 46.23$$

$$s = w\sqrt{\frac{n\sum fz^2 - (\sum fz)^2}{n(n-1)}} = 3\sqrt{\frac{88(318) - (36)^2}{88(87)}} = 5.60$$

Other parameters were picked off the percent cumulative f curve (Fig. 18).

Statistical Comparisons

The following illustrates the methods for making comparisons between the means and standard deviations of the sample just processed and the "night" before sample at the same station.

Summary of processed data:	Night	After
n	142	88
$\bar{X}$	45.51	46.23
s	5.63	5.60

Example 3: Comparison of Standard Deviations (or Variances).

Level of significance chosed at five percent level.

$$F_o = \frac{5.63^2}{5.60^2} = 1.01$$

From a table of values of the F distribution for 2.5 percent points*, i.e., 2.5 percent area (probability) above F_c (2.5 percent at each side = 5 percent) for 141 degrees of freedom in the caption and 87 degrees of freedom in the stub, we find

$$F_{.025,\ (141,\ 87)} = 1.47$$

Since $F_o = 1.01$ is less than $F_c = 1.47$ we have no reliable evidence for rejecting the hypothesis that the standard deviations are equal. We may conclude that there is no significance to the observed difference.

---

*Some tables are headed "97.5 percent fractiles" to denote values with 2.5 percent probability above F_c.

(Ex. 2, continued)

The 85th percentile speed is read directly from the curve; a ten mile per hour pace and the percent in this pace were obtained by a process of trial and error.

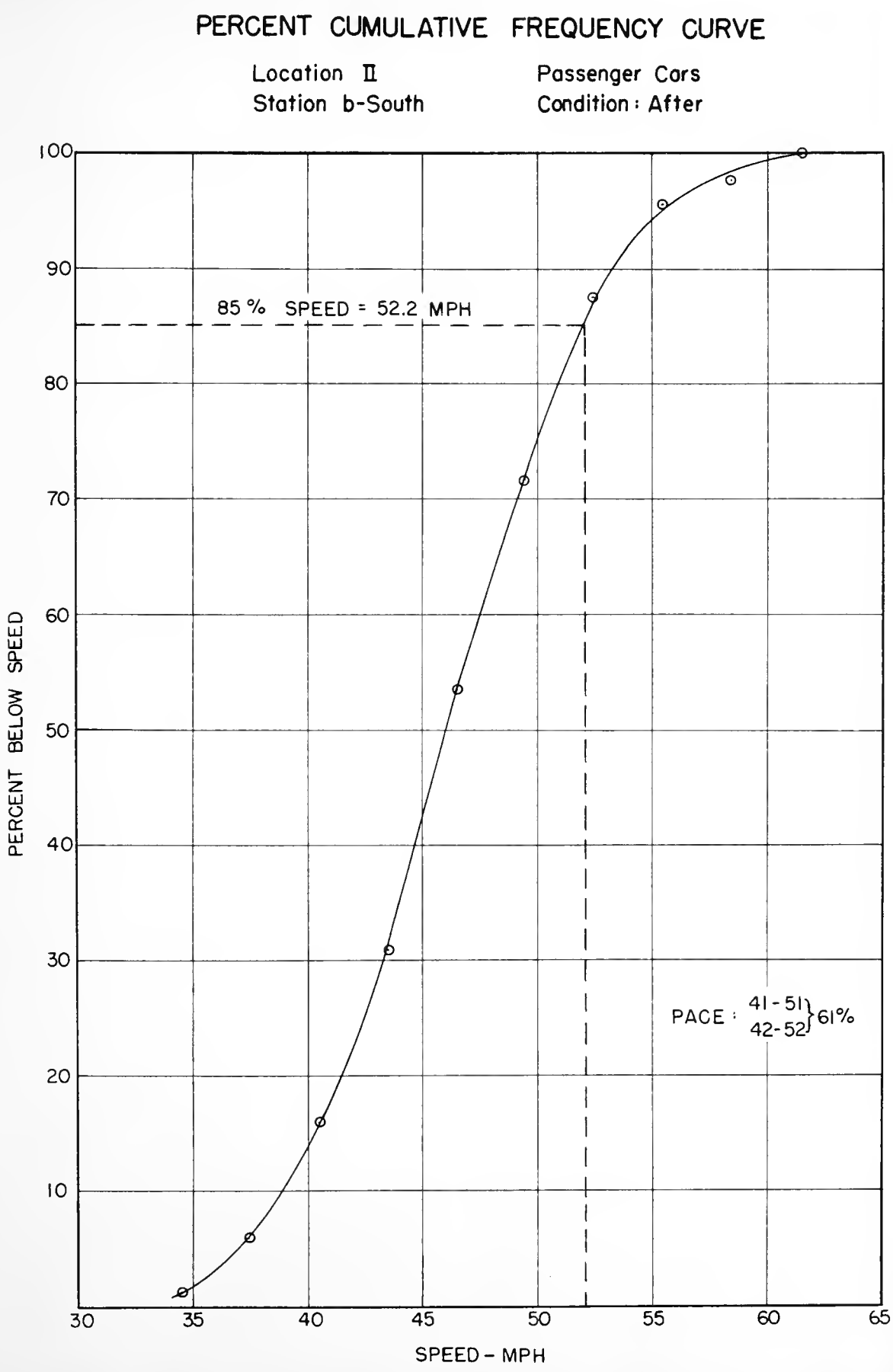


FIGURE 18

Example 4: Comparison of Difference of Means.

Level of significance chosen at five percent level.

$$t_o = \frac{46.23 - 45.51}{\sqrt{\frac{5.63^2}{88} + \frac{5.60^2}{142}}} = \frac{0.72}{0.76} = 0.95$$

From a table of values for the t distribution for 97.5 percent points (2.5 percent at each side) and 228 degrees of freedom we find

$$t_{.975,228} = 1.97$$

$$t_{.025,228} = -1.97$$

Since $-1.97 < 0.95 < 1.97$ we have no reliable evidence for rejecting the hypothesis that the means differ. We may conclude that there is no significance to the observed difference.

However, if it should happen that there actually is a true difference in the population means of two miles per hour, our decision not to reject the hypothesis would be incorrect. The probability that the observed difference came from a population with $\delta = 2$ is $\beta(2)$. From Figure 19 we find this to be equal to 0.25. The power of this test, for a difference of two miles per hour, is 1 - 0.25 or 75 percent. Similarly the probability of our having made an incorrect decision for a difference of three miles per hour is 0.02 and the power of this test for $\delta = 3$ is 98 percent.

POWER CURVES

FOR TEST OF HYPOTHESIS: $\delta = \mu_2 - \mu_1 = 0$

Two sided test, $\alpha = 5\%$

$\beta(\delta)$ = Probability of failing to reject false hypothesis; i.e. probability that $-t_c < t_o < t_c$ when actual difference not equal to zero.

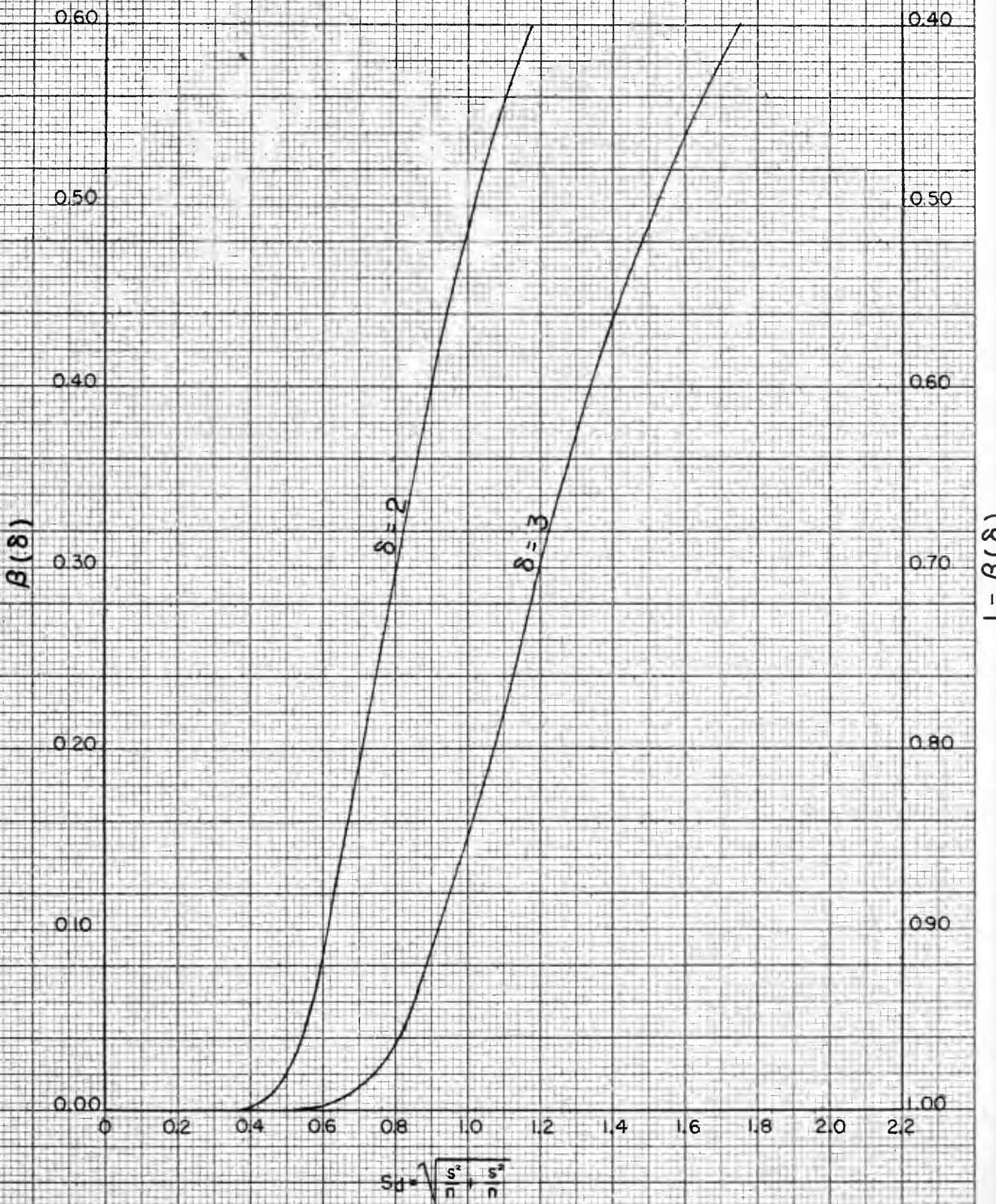


FIGURE 19

Example 5: Comparison of Combined Variances.

Summary of processed data (same station as before, night before phase):

	Passenger cars	Trucks
n	142	88
$\bar{X}$	45.51	38.49
s	5.63	4.22

$$\bar{X}_c = \frac{142\ (45.51) + 88\ (38.49)}{142 + 88} = 42.82$$

$$s_c^2 = \frac{142(5.63)^2 + 88(4.22)^2 + 142(45.51 - 42.82)^2 + 88(38.49 - 42.82)^2}{142 + 88 - 2}$$

$$= 38.14$$

Similarly, s_c^2 for the after sample was calculated and the two variances were compared by means of the F test. The procedure for this test is exactly the same as that used in testing the separate variances.

APPENDIX B

LIST OF TABLES

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TABLE 1

SUMMARY OF PROCESSED DATA

Station	Condition	n	mph $\bar{X}$	s	P_{85}	Pace	Percent in Pace
		Location I: Northbound Cars					
a	Day	144	54.5	6.8	61.5	48-59	56 1/2
	Night	115	52.9	7.6	59.5	48-58	55
	After	132	54.0	9.2	62.8	45-55	49
b	D	221	49.5	7.7	57.9	44-54	47 1/2
	N	85	49.7	9.8	58.5	47-57	39
	A	162	50.1	9.1	60.0	42-54	43
c	D	203	44.3	8.2	53.5	35-49	42
	N	172	44.1	8.0	52.0	37-47	50
	A	125	47.3	9.0	56.5	40-52	48
d	D	197	45.9	7.3	54.0	39-51	53
	N	145	47.3	8.3	55.5	46-56	44
	A	238	46.5	9.8	55.5	42-52	39
e	D	109	38.7	5.6	44.2	34-44	66
	N	128	36.2	5.2	41.8	30-40	66
	A	168	37.6	5.6	43.5	32-42	70
f	D	105	39.7	5.3	45.0	35-45	72
	N	70	40.8	6.2	48.0	35.5-45.5	58
	A	141	38.7	5.8	44.5	31-43	67
		Location I: Southbound Cars					
a	D	128	51.8	7.2	59.5	49-60	47
	N	123	50.1	7.7	59.1	42-54	48
	A	137	51.7	8.0	60.0	48-59	43
b	D	178	47.2	7.2	55.2	41-51	53
	N	108	48.7	8.3	58.0	41-51	52
	A	170	48.6	8.3	58.5	41-51	45
c	D	160	42.6	8.6	51.8	32-46	45
	N	153	40.8	8.2	49.5	32-46	46 1/2
	A	140	45.5	8.3	53.5	41-51	48

continued next page

Table 1, continued

Station	Condition	n	mph $\bar{X}$	s	P_{85}	Pace	Percent in Pace
d	D	103	42.4	7.4	51.1	35-46	48
	N	135	43.7	8.7	52.5	35-49	44
	A	208	45.3	8.9	54.5	39-51	46
e	D	140	40.3	6.2	46.7	33-43	57
	N	178	36.6	4.9	41.5	32-42	68
	A	142	36.0	5.2	41.5	30-41	69
f	D	90	42.0	5.8	48.0	36-47	62
	N	78	40.2	5.0	45.3	36-46	72
	A	125	39.0	5.7	43.8	33-44	67
		Location II: Northbound Cars					
a	D	146	57.8	6.7	64.5	54.5-64.5	59
	N	98	56.5	6.9	62.3	52-62	58
	A	190	57.9	7.1	65.2	52.5-63	53
b	D	180	51.3	5.7	57.5	45-58	56
	N	135	49.2	5.9	54.5	44.5-54.5	64 1/2
	A	116	50.4	6.0	55.8	45.5-56	63
c	D	369	45.7	5.3	51.0	42-52	71
	N	135	44.0	5.3	49.6	40-51	64
	A	128	42.4	6.3	48.5	38-48	57
d	D	165	43.2	5.7	49.4	39-49	60
	N	144	40.0	6.2	47.5	31.5-41.5	48
	A	71	41.1	6.4	48.3	35-47	53
e	D	133	35.8	6.3	42.6	30-40	57
	N	127	34.8	5.2	39.5	29-39	70
	A	111	34.3	4.4	39.4	28.5-38.5	77
f	D	138	50.2	5.2	55.2	46-56	72
	N	378	46.4	7.0	53.8	41-51	52
	A	257	48.0	5.5	53.5	43-53.5	68
g	D	118	57.8	6.4	63.5	53-63	67
	N	112	51.9	7.2	59.7	44-54	51
	A	162	55.2	7.2	62.5	48.5-59	56
i	D	237	57.3	7.6	65.5	55-65	44
	N	140	52.3	7.2	59.0	49-59	51
	A	140	56.1	8.5	64.0	53-63	49
j	D	168	57.8	7.2	64.5	51-65	48
	N	143	55.2	8.0	63.5	51-62	50
	A	136	55.7	8.1	63.8	52.5-62.5	48 1/2

continued next page

Table 1, continued

Station	Condition	n	mph $\bar{X}$	s	P_{85}	Pace	Percent in Pace
			Location II: Southbound Cars				
a	D	129	55.2	6.4	61.1	51-61	60
	N	115	53.1	6.7	60.2	45-56	53
	A	251	55.2	7.1	62.5	49-59	56
b	D	206	48.8	5.8	54.3	44-55	60
	N	142	45.5	5.6	51.5	41-51	63
	A	88	46.2	5.6	52.2	41-52	61
c	D	288	41.7	4.9	46.5	37-47	72
	N	118	37.8	5.0	43.2	32-42	72
	A	143	40.7	4.7	44.5	35.5-45.5	78 1/2
d	D	100	40.5	5.9	46.5	35-47	58
	N	135	40.2	4.9	45.5	35-45.5	70
	A	73	38.1	5.9	43.7	32.5-43.5	65
e	D	125	36.6	5.1	42.0	31-41	69
	N	115	32.6	5.3	38.5	27.5-37.5	67 1/2
	A	116	33.5	4.9	38.3	27.5-38	70 1/2
f	D	130	51.3	5.9	57.2	46-56	64
	N	450	46.0	6.8	52.5	40-50	57
	A	223	47.3	5.7	53.5	40.5-50.5	63 1/2
g	D	93	57.3	6.1	63.5	51-62	64
	N	110	54.6	7.6	62.5	47-57	51
	A	153	55.1	8.3	64.3	49-60	45
h	D	192	37.1	4.6	41.5	32-42	74
	N	120	32.2	4.4	36.5	28-38	77
	A	65	33.9	5.7	40.2	29.5-39.5	66 1/2
i	D	253	54.2	6.8	60.5	51-62	60
	N	108	49.8	8.1	59.5	40.5-50.5	47
	A	186	52.8	7.0	60.0	48-58.5	54
j	D	176	53.5	7.0	60.6	47-57	55 1/2
	N	232	50.9	7.2	57.7	47-57	56
	A	172	53.6	7.3	61.0	47-59	49
			Location III: Northbound Cars				
a	D	177	54.1	8.2	62.5	49-59	52
	N	116	53.5	9.1	61.5	48-59	49
	A	197	54.6	7.6	62.5	50-60	48 1/2

continued next page

Table 1, continued

Station	Condition	n	mph $\bar{X}$	s	P_{85}	Pace	Percent in Pace
b	D	187	50.5	7.5	58.0	44-56	50
	N	124	47.8	6.7	54.6	44-55	52
	A	157	51.9	7.1	59.0	46-57	55
f	D	161	55.2	6.7	61.5	49-59	59
	N	119	56.9	7.8	63.0	52-63	56
	A	295	55.9	8.6	65.0	51-62	43
g	D	125	54.8	7.1	61.8	49-59	54
	N	132	52.9	7.6	59.6	49-59	56
	A	320	51.1	7.8	59.0	45-56	50
h	D	188	49.4	7.1	56.8	47-57	50
	N	103	45.6	6.8	52.5	42-52	55
	A	198	48.9	7.7	56.5	45-56	53
i	D	161	42.9	6.7	49.8	48.5-58.5	55
	N	109	38.5	6.6	44.2	34.5-44.5	64
	A	246	41.0	7.6	49.5	36-47	50
j	D	77	44.2	8.3	51.8	38-48	50
	N	74	39.7	5.9	46.5	32.5-42.5	57
	A	197	40.4	7.4	47.0	34-44	55
		Location III: Southbound Cars					
a	D	153	54.7	8.0	62.5	50-60	50
	N	126	51.6	8.2	59.0	48-58	53
	A	181	54.3	8.3	61.5	51-62	50
b	D	164	52.8	7.0	60.1	50-62	52
	N	139	48.1	8.9	56.7	46-56	47 1/2
	A	159	52.4	8.9	62.3	46-57	41
c	D	196	50.9	6.5	56.8	47-57	60
	N	113	46.3	8.0	54.0	43-55	44
	A	219	49.3	7.6	57.5	44-56	48
d	D	283	54.8	7.8	62.5	49-59	54
	N	207	53.4	8.6	62.5	44-54	43
	A	359	52.3	8.3	61.0	48-59	45
e	D	154	56.1	8.7	65.2	50-62	44
	N	201	53.5	9.0	61.5	51-61	51
	A	244	55.9	8.5	64.5	50-61	45
j	D	79	38.9	6.3	44.5	34-44	61
	N	81	37.2	6.6	44.5	30-40	63
	A	202	37.0	5.4	43.0	30-40	67

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Table 1, continued

Station	Condition	n	mph $\bar{X}$	s	P_{85}	Pace	Percent in Pace
		Location II: Northbound Trucks					
a	D	53	49.5	5.3	55.5	43-54	71
	N	56	49.3	4.4	53.7	44.5-54.5	80
	A	71	48.5	3.8	52.2	43.5-53.5	82 1/2
b	D	23	46.1	2.8	49.3	41.5-51.5	96
	N	52	43.9	4.6	47.2	38-48	79 1/2
	A	93	45.1	4.3	49.7	41-51	76
c	D	63	40.5	5.3	46.0	36-46	68 1/2
	N	33	43.2	3.5	47.0	37-47	85 1/2
	A	95	42.9	4.9	47.8	38-48.5	68
d	D	38	43.7	5.1	48.8	39-49	63 1/2
	N	114	41.2	5.2	46.8	38-48.5	74
	A	59	41.8	4.6	46.3	37-47	76 1/2
e	D	20	37.9	3.1	40.3	31.5-42	89 1/2
	N	43	38.5	3.5	41.7	32.5-43	86
	A	70	37.5	5.0	42.2	33-43	71 1/2
f	D	41	37.5	5.0	43.0	32-44	62
	N	78	41.8	5.8	47.8	38-48	62
	A	105	39.5	5.8	45.2	36-46	64
g	D	32	45.7	4.9	50.8	40-51	71
	N	65	48.1	4.9	53.0	42.5-53.5	73
	A	138	47.3	3.8	51.0	42.5-52.5	85
i	D	36	46.6	4.8	51.2	43.5-53.5	79
	N	54	46.0	3.9	50.5	41.5-51.5	80
	A	47	44.2	5.3	49.3	39-49	70 1/2
j	D	33	48.9	4.1	53.3	43-54	76
	N	29	46.0	4.5	51.3	42-52	75
	A	40	46.9	4.7	50.2	42-52	81
		Location II: Southbound Trucks					
a	D	57	45.3	3.6	49.3	40-51	79
	N	75	43.5	4.4	47.5	38.5-48.5	80 1/2
	A	102	41.9	4.3	46.0	35-46	76 1/2
b	D	46	41.4	4.4	45.8	36.5-47	78
	N	88	38.5	4.2	42.8	33.5-45	75 1/2
	A	134	37.9	4.2	42.0	33-43	78

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Table 1, continued

Station	Condition	n	mph $\bar{X}$	s	P_{85}	Pace	Percent in Pace
c	D	66	36.9	4.3	41.5	33-43	79
	N	71	36.1	4.9	41.5	32-42.5	68
	A	147	37.9	4.3	42.4	32.5-43	75
d	D	56	38.2	4.4	42.5	34-44	73 1/2
	N	97	38.4	4.8	42.4	33.5-43.5	78
	A	80	37.9	4.5	41.7	32-42.5	76 1/2
e	D	45	37.6	4.5	42.5	33-43	74
	N	67	36.3	4.7	41.3	30-41	71
	A	97	37.4	4.5	42.3	32.5-43	73
f	D	53	42.6	4.9	48.0	38-49	69
	N	148	42.7	5.3	48.5	37.5-48.5	67
	A	175	42.1	4.5	46.3	37-47.5	74
g	D	46	47.3	5.0	52.0	43-53	71 1/2
	N	73	48.1	4.0	52.6	43-53	90
	A	190	48.5	4.6	53.1	42.5-53	74
h	D	47	37.2	5.1	42.5	32-43	64
	N	78	34.6	5.3	40.0	29.5-40.5	66
	A	50	37.5	3.9	41.4	33.5-43.5	81
i	D	64	44.3	4.5	48.2	39.5-49.5	78 1/2
	N	80	42.2	4.1	46.5	36.5-47.5	77
	A	66	40.1	4.8	44.8	35-45	77
j	D	57	46.5	4.7	51.0	42-52	76
	N	91	44.3	3.8	48.5	39.5-49.5	84
	A	66	42.4	4.2	46.2	37-48	82 1/2

n: Number of observations in sample

$\bar{X}$: Sample mean

s: Sample standard deviation

P_{85}: Sample eighty-fifth percentile speed

TABLE 2

TESTS ON DIFFERENCES BETWEEN MEANS

Two-sided test; $\alpha = 0.05$

Station	Mean Speeds by Condition (mph)			DAY - NIGHT COMPARISON				NIGHT - AFTER COMPARISON			
				Test		Result		Test		Result	
	D	N	A	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$
				Location I: Northbound Cars							
a	54.5	52.9	54.0	-1.80	1.97	0.92	0.61	1.04	1.97	0.81	0.46
b	49.5	49.7	50.1	0.20	1.99	0.72	0.40	0.30	1.97	0.66	0.39
c	44.3	44.1	47.3	-0.22	1.97	0.95	0.66	3.16	1.97	S	
d	45.9	47.3	46.5	1.71	1.97	0.94	0.66	-0.87	1.97	0.89	0.56
e	38.7	36.2	37.6	-3.52	1.97	S		2.11	1.97	S	
f	39.7	40.8	38.7	1.32	1.97	0.93	0.63	-2.46	1.97	S	
				Location I: Southbound Cars							
a	51.8	50.1	51.7	-1.85	1.97	0.89	0.56	1.65	1.97	0.87	0.52
b	47.2	48.7	48.6	1.65	1.97	0.90	0.57	-0.11	1.97	0.84	0.50
c	42.6	40.8	45.5	-1.90	1.97	0.88	0.54	4.89	1.97	S	
d	42.4	43.7	45.3	1.19	1.97	0.81	0.46	1.69	1.97	0.87	0.52

continued next page

Table 2, continued

Station	Mean Speeds by Condition (mph)			DAY - NIGHT COMPARISON				NIGHT - AFTER COMPARISON			
				Test		Result		Test		Result	
	D	N	A	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$
e	40.3	36.6	36.0	-5.77	1.97	S		-1.13	1.97	0.99	0.94
f	42.0	40.2	39.0	-2.20	1.97	S		-1.44	1.97	0.97	0.72
				Location II: Northbound Cars							
a	57.8	56.5	57.9	-1.40	1.97	0.92	0.62	1.53	1.97	0.93	0.63
b	51.3	49.2	50.4	-3.14	1.97	S		1.66	1.97	0.98	0.76
c	45.7	44.0	42.4	-3.18	1.97	S		-2.26	1.97	S	
d	43.2	40.0	41.1	-4.80	1.97	S		1.23	1.97	0.91	0.59
e	35.8	34.8	34.3	-1.43	1.97	0.99	0.80	-0.83	1.97	0.99	0.89
f	50.2	46.4	48.0	-6.58	1.97	S		3.31	1.97	S	
g	57.8	51.9	55.2	-6.62	1.97	S		3.80	1.97	S	
i	57.3	52.3	56.1	-6.23	1.97	S		4.05	1.97	S	
j	57.8	55.2	55.7	-3.03	1.97	S		0.60	1.97	0.87	0.54
				Location II: Southbound Cars							
a	55.2	53.1	55.2	-2.49	1.97	S		2.66	1.97	S	
b	48.8	45.5	46.2	-5.19	1.97	S		0.95	1.97	0.98	0.74
c	41.7	37.8	40.7	-7.35	1.97	S		4.93	1.97	S	

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Table 2, continued

Station	Mean Speeds by Condition (mph)			DAY - NIGHT COMPARISON				NIGHT - AFTER COMPARISON			
				Test		Result		Test		Result	
	D	N	A	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$
d	40.5	40.2	38.1	-0.39	1.97	0.99	0.79	-2.74	1.97	S	
e	36.6	32.6	33.5	-5.92	1.97	S		1.32	1.97	0.99	0.85
f	51.3	46.0	47.3	-8.13	1.97	S		2.62	1.97	S	
g	57.3	54.6	55.1	-2.82	1.97	S		0.53	1.97	0.85	0.52
h	37.1	32.2	33.9	-9.37	1.97	S		2.11	1.97	S	
i	54.2	49.8	52.8	-4.97	1.97	S		3.36	1.97	S	
j	53.5	50.9	53.6	-3.66	1.97	S		3.64	1.97	S	
				Location III: Northbound Cars							
a	54.1	53.5	54.6	-0.62	1.97	0.84	0.50	1.13	1.98	0.85	0.52
b	50.5	47.8	51.9	-3.27	1.97	S		4.88	1.97	S	
f	55.2	56.9	55.9	2.02	1.97	S		-1.18	1.97	0.91	0.59
g	54.8	52.9	51.1	-2.00	1.97	S		-2.33	1.97	S	
h	49.4	45.6	48.9	-4.43	1.97	S		3.71	1.97	S	
i	42.9	38.5	41.0	-5.30	1.97	S		2.97	1.97	S	
j	44.2	39.7	40.4	-3.88	1.99	S		0.83	1.99	0.93	0.63

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Table 2, continued

Station	Mean Speeds by Condition (mph)			DAY - NIGHT COMPARISON				NIGHT - AFTER COMPARISON			
				Test		Result		Test		Result	
	D	N	A	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$
Location III: Southbound Cars											
a	54.7	51.6	54.3	-3.21	1.97	S		2.79	1.97	S	
b	52.8	48.1	52.4	-5.03	1.97	S		4.13	1.97	S	
c	50.9	46.3	49.3	-5.16	1.97	S		3.31	1.97	S	
d	54.8	53.4	52.3	-1.80	1.97	0.98	0.76	-1.57	1.97	0.98	0.78
e	56.1	53.5	55.9	-2.72	1.97	S		2.90	1.97	S	
j	38.9	37.2	37.0	-1.68	1.97	0.84	0.50	-0.30	1.99	0.95	0.68
Location II: Northbound Trucks											
a	49.5	49.3	48.5	-0.19	1.98	0.90	0.57	-1.07	1.98	0.98	0.78
b	46.1	43.9	45.1	-2.63	2.04	S		1.58	1.97	0.98	0.75
c	40.5	43.2	42.9	3.07	2.02	S		-0.50	2.01	0.97	0.72
d	43.7	41.2	41.8	-2.53	1.97	S		0.69	1.98	0.96	0.71
e	37.9	38.5	37.5	0.69	2.00	0.90	0.57	-1.31	2.00	0.96	0.70
f	37.5	41.8	39.5	4.07	1.98	S		-2.66	1.98	S	
g	45.7	48.1	47.3	2.22	1.99	S		-1.07	1.99	0.99	0.83
i	46.6	46.0	44.2	-0.61	1.98	0.90	0.57	-1.96	2.01	0.90	0.57
j	48.9	46.0	46.9	-2.65	2.00	S		0.84	2.00	0.76	0.42

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Table 2, continued

Station	Mean Speeds by Condition (mph)			DAY - NIGHT COMPARISON				NIGHT - AFTER COMPARISON			
				Test		Result		Test		Result	
	D	N	A	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$	t_o	t_c	$1-\beta(3)$	$1-\beta(2)$
				Location II: Southbound Trucks							
a	45.3	43.5	41.9	-2.45	1.98	S		-2.44	1.97	S	
b	41.4	38.5	37.9	-3.67	1.98	S		-1.09	1.97	0.99	0.93
c	36.9	36.1	37.9	-0.94	1.98	0.97	0.72	2.68	1.97	S	
d	38.2	38.4	37.9	0.24	1.98	0.97	0.73	-0.71	1.97	0.99	0.81
e	37.6	36.3	37.4	-1.49	1.98	0.92	0.62	1.50	1.98	0.99	0.79
f	42.6	42.7	42.1	0.22	1.97	0.95	0.68	-1.12	1.98	0.99	0.93
g	47.3	48.1	48.5	0.97	1.98	0.95	0.68	0.69	1.97	0.99	0.90
h	37.2	34.6	37.5	-2.70	1.98	S		3.55	2.00	S	
i	44.3	42.2	40.1	-2.90	1.98	S		-2.80	1.98	S	
j	46.5	44.3	42.4	-3.13	1.98	S		-2.95	1.98	S	

TABLE 3

TESTS ON CHANGES IN VARIANCES

Two-sided test: $\alpha = 0.05$

Station	Standard Deviations by Condition (mph)			DAY - NIGHT COMPARISON			NIGHT - AFTER COMPARISON		
				Test		Result	Test		Result
	D	N	A	F_o	F_c		F_o	F_c	
Location I: Northbound Cars									
a	6.8	7.6	9.2	1.23	1.41	-	1.47	1.43	S
b	7.7	9.8	9.1	1.61	1.41	S	1.15	1.43	-
c	8.2	8.0	9.0	1.04	1.33	-	1.27	1.38	-
d	7.3	8.3	9.8	1.27	1.35	-	1.41	1.35	S
e	5.6	5.2	5.6	1.14	1.43	-	1.13	1.39	-
f	5.3	6.2	5.8	1.37	1.52	-	1.15	1.48	-
Location I: Southbound Cars									
a	7.2	7.7	8.0	1.15	1.42	-	1.06	1.42	-
b	7.2	8.3	8.3	1.32	1.39	-	1.01	1.41	-
c	8.6	8.2	8.3	1.12	1.36	-	1.03	1.41	-
d	7.4	8.7	8.9	1.40	1.45	-	1.04	1.36	-
e	6.2	4.9	5.2	1.61	1.36	S	1.15	1.35	-
f	5.8	5.0	5.7	1.37	1.54	-	1.32	1.51	-
Location II: Northbound Cars									
a	6.7	6.9	7.1	1.05	1.43	-	1.08	1.43	-
b	5.7	5.9	6.0	1.04	1.37	-	1.06	1.43	-
c	5.3	5.3	6.3	1.03	1.34	-	1.44	1.41	S
d	5.7	6.2	6.4	1.17	1.37	-	1.09	1.48	-
e	6.3	5.2	4.4	1.46	1.41	S	1.43	1.44	-
f	5.2	7.0	5.5	1.82	1.34	S	1.64	1.26	S
g	6.4	7.2	7.2	1.28	1.45	-	1.01	1.40	-
i	7.6	7.2	8.5	1.12	1.35	-	1.40	1.39	S
j	7.2	8.0	8.1	1.26	1.37	-	1.02	1.39	-

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Table 3, continued

Station	Standard Deviations by Condition (mph) D	N	A	DAY - NIGHT COMPARISON Test F_o	F_c	Result	NIGHT - AFTER COMPARISON Test F_o	F_c	Result
				Location II: Southbound Cars					
a	6.4	6.7	7.1	1.11	1.43	-	1.13	1.39	-
b	5.8	5.6	5.6	1.08	1.36	-	1.01	1.47	-
c	4.9	5.0	4.7	1.04	1.35	-	1.15	1.41	-
d	5.9	4.9	5.9	1.45	1.44	S	1.47	1.48	-
e	5.1	5.3	4.9	1.07	1.44	-	1.16	1.45	-
f	5.9	6.8	5.7	1.30	1.34	-	1.41	1.27	S
g	6.1	7.5	6.3	1.53	1.49	S	1.19	1.42	-
h	4.6	4.4	5.7	1.11	1.39	-	1.66	1.52	S
i	6.8	8.1	7.0	1.43	1.36	S	1.33	1.39	-
j	7.0	7.2	7.3	1.07	1.33	-	1.02	1.32	-
				Location III: Northbound Cars					
a	8.2	9.1	7.6	1.24	1.39	-	1.46	1.38	S
b	7.5	6.7	7.1	1.25	1.39	-	1.12	1.40	-
f	6.7	7.8	8.6	1.37	1.39	-	1.21	1.38	-
g	7.1	7.6	7.8	1.14	1.42	-	1.05	1.35	-
h	7.1	6.8	7.7	1.28	1.42	-	1.26	1.42	-
i	6.7	6.6	7.6	1.02	1.42	-	1.33	1.40	-
j	8.3	5.9	7.4	1.93	1.58	S	1.57	1.48	S
				Location III: Southbound Cars					
a	8.0	8.2	8.3	1.07	1.39	-	1.02	1.39	-
b	7.0	8.9	8.9	1.62	1.37	S	1.00	1.38	-
c	6.5	8.0	7.6	1.54	1.38	S	1.13	1.36	-
d	7.8	8.6	8.3	1.20	1.38	-	1.07	1.27	-
e	8.7	9.0	8.5	1.07	1.34	-	1.13	1.30	-
j	6.3	6.6	5.4	1.11	1.55	-	1.46	1.42	S

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Table 3, continued

Station	Standard Deviations by Condition (mph)			DAY - NIGHT COMPARISON			NIGHT - AFTER COMPARISON		
				Test		Result	Test		Result
	D	N	A	F_o	F_e		F_o	F_c	
Location II: Northbound Trucks									
a	5.3	4.4	3.8	1.49	1.72	-	1.29	1.65	-
b	2.8	4.6	4.3	2.65	2.14	S	1.13	1.61	-
c	5.3	3.5	4.9	2.30	1.90	S	1.96	1.85	S
d	5.1	5.2	4.6	1.02	1.75	-	1.27	1.60	-
e	3.1	3.5	5.0	1.27	2.28	-	1.97	1.75	S
f	5.0	5.8	5.8	1.32	1.76	-	1.01	1.52	-
g	4.9	4.9	3.8	1.03	1.79	-	1.60	1.49	S
i	4.8	3.9	5.3	1.54	1.30	-	1.82	1.73	S
j	4.1	4.5	4.7	1.24	2.04	-	1.09	2.03	-
Location II: Southbound Trucks									
a	3.6	4.4	4.3	1.45	1.64	-	1.04	1.52	-
b	4.4	4.2	4.2	1.09	1.63	-	1.01	1.45	-
c	4.3	4.9	4.3	1.30	1.61	-	1.28	1.47	-
d	4.4	4.8	4.5	1.20	1.62	-	1.11	1.53	-
e	4.5	4.7	4.5	1.09	1.74	-	1.09	1.55	-
f	4.9	5.3	4.5	1.18	1.62	-	1.37	1.35	S
g	5.0	4.0	4.6	1.58	1.67	-	1.36	1.49	-
h	5.1	5.3	3.9	1.08	1.71	-	1.83	1.69	S
i	4.5	4.1	4.8	1.19	1.58	-	1.38	1.58	-
j	4.7	3.8	4.2	1.50	1.60	-	1.23	1.56	-
Location II: Northbound Combined (Cars and Trucks)									
a	7.4	7.0	7.7	1.11	1.35	-	1.20	1.34	-
b	5.7	6.0	5.9	1.10	1.33	-	1.02	1.33	-
c	5.6	5.0	5.7	1.29	1.30	-	1.33	1.33	S

continued next page

Table 3, continued

Station	Standard Deviations by Condition (mph)			DAY - NIGHT COMPARISON			NIGHT - AFTER COMPARISON		
				Test		Result	Test		Result
	D	N	A	F_o	F_c		F_o	F_c	
d	5.6	5.8	5.7	1.07	1.31	-	1.03	1.37	-
e	6.0	5.1	4.9	1.39	1.36	S	1.11	1.34	-
f	7.4	7.0	6.8	1.12	1.27	-	1.08	1.23	-
g	7.9	6.7	7.1	1.38	1.36	S	1.12	1.32	-
i	8.2	7.0	9.4	1.35	1.31	S	1.78	1.33	S
j	7.5	8.3	8.4	1.22	1.34	-	1.01	1.35	-
				Location II: Southbound Combined (Cars and Trucks)					
a	7.3	7.6	8.8	1.07	1.33	-	1.37	1.30	S
b	6.3	6.2	6.3	1.04	1.30	-	1.05	1.30	-
c	5.2	5.0	4.7	1.06	1.30	-	1.13	1.29	-
d	5.5	4.9	5.2	1.25	1.32	-	1.13	1.34	-
e	4.9	5.3	5.1	1.17	1.34	-	1.11	1.32	-
f	6.9	6.6	5.8	1.11	1.26	-	1.28	1.21	S
g	7.5	7.1	7.3	1.09	1.36	-	1.04	1.31	-
h	4.7	4.9	5.3	1.08	1.30	-	1.16	1.38	-
i	7.5	7.7	8.6	1.04	1.28	-	1.25	1.32	-
j	7.2	7.1	8.3	1.02	1.27	-	1.36	1.27	S

S : test was significant

- : test was not significant

TABLE 4

TESTS ON CHANGES IN $\bar{t}_o$ AT ZONES

Zone	n	$\bar{t}_o$	$s_{\bar{t}_o}$	t'	t_c α=.05	Result	t_c α=.10	Result
				DAY - NIGHT				
Open Highway Approaching	5	-2.35	0.32	-7.38	2.77	S		
Other	28	-3.22	0.57	-5.60	2.05	S		
Critical	16	-3.49	0.78	-4.49	2.13	S		
Approach	7	-3.17	0.97	-3.28	2.45	S		
Recovery	6	-2.64	1.44	-1.83	2.57	-	2.02	-
Open Highway Leaving	6	-2.64	1.15	-2.29	2.57	-	2.02	S
				NIGHT - AFTER				
Open Highway Approaching	5	1.32	0.43	3.04	2.77	S		
Other	28	1.20	0.46	2.60	2.05	S		
Critical	16	1.48	0.60	2.45	2.13	S		
Approach	7	1.04	0.86	1.21	2.45	-	1.94	-
Recovery	6	0.58	1.13	0.52	2.57	-	2.02	-
Open Highway Leaving	6	2.23	0.75	3.00	2.57	S		

n : number of stations tested for each type of zone

$\bar{t}_o$: average of $\bar{t}_o$ for given stations

$s_{\bar{t}_o}$: standard deviation of distribution of $\bar{t}_o$ (standard error of $\bar{t}_o$)

t' : test statistic for $\bar{t}_o$

S : test was significant

- : test was not significant

TABLE 5

TESTS ON DIFFERENCES IN $\bar{t}_o$ BETWEEN ZONES

Zones Compared	n_1	n_2	$\bar{t}_{o_2} - \bar{t}_{o_1}$	$s_{\Delta \bar{t}_o}$	t'	Result
			DAY - NIGHT			
OHA - Other	5	28	-0.86	1.38	-0.62	-
OHA - Critical	5	16	-1.14	1.43	-0.80	-
OHA - Approach	5	7	-0.82	1.19	-0.69	-
OHA - Recovery	5	6	-0.28	1.62	-0.18	-
OHA - OHL	5	6	-0.28	1.30	-0.22	-
Approach - Critical	7	16	-0.32	1.34	-0.23	-
Critical - Recovery	16	6	0.85	1.54	0.55	-
Recovery - OHL	6	6	0.00	1.84	0.00	-
Approach - Recovery	7	6	0.54	1.69	0.32	-
			NIGHT - AFTER			
OHA - Other	5	28	-0.12	1.12	-0.11	-
OHA - Critical	5	16	0.16	1.12	-0.14	-
OHA - Approach	5	7	-0.28	1.10	-0.26	-
OHA - Recovery	5	6	-0.74	1.31	-0.56	-
OHA - OHL	5	6	0.91	0.92	0.99	-
Approach - Critical	7	16	0.44	1.08	0.40	-
Critical - Recovery	16	6	-0.89	1.20	-0.74	-
Recovery - OHL	6	6	1.65	1.36	1.21	-
Approach - Recovery	7	6	-0.46	1.40	-0.33	-

OHA: Open Highway - Approaching

OHL: Open Highway - Leaving